



Surgeon General's Office

LIBRARY

Chemistry
Section, Shelf,

No. 28058

PRESENTED BY

Dr John Green

Gran Heywood

JOHN GREEN.
THE
ELEMENTS
OF
CHEMICAL SCIENCE.
IN TWO VOLUMES.
WITH PLATES.

BY JOHN GORHAM, M. D.

MEMBER OF THE AMERICAN ACADEMY, AND PROFESSOR OF CHEMISTRY
IN HARVARD UNIVERSITY, CAMBRIDGE.

Homo naturæ minister et interpres.
Bacon.

VOL. I.

28058
BOSTON:

PUBLISHED BY CUMMINGS AND HILLIARD, AT THE BOSTON
BOOKSTORE, NO. 1 CORNHILL.

University press.....Hilliard & Metcalf.

1819.

DISTRICT OF MASSACHUSETTS, TO WIT:

District Clerk's Office.

BE IT REMEMBERED, That on the fifth day of January, A. D. 1819, and in the forty third year of the Independence of the United States of America, JOHN GORHAM, M. D. of the said District, has deposited in this office, the title of a Book, the right whereof he claims as Author, in the words following, viz.

"The Elements of Chemical Science. In two volumes. With plates. By John Gorham, M. D. Member of the American Academy, and professor of Chemistry in Harvard University, Cambridge. Homo naturæ minister et interpres.—*Bacon*. Vol. 1."

In conformity to the act of the Congress of the United States, entitled, "An act for the encouragement of learning, by securing the copies of maps, charts, and books, to the authors and proprietors of such copies, during the times therein mentioned;" and also to an act, entitled, "An act supplementary to an act, entitled, an act for the encouragement of learning, by securing the copies of maps, charts, and books, to the authors and proprietors of such copies during the times therein mentioned; and extending the benefits thereof to the arts of designing, engraving and etching historical and other prints."

JNO. W. DAVIS,

Clerk of the District of Massachusetts.

TO

AARON DEXTER, M. D.

EMERITUS PROFESSOR OF CHEMISTRY IN HARVARD
UNIVERSITY,

THIS WORK

IS GRATEFULLY DEDICATED,

BY

THE AUTHOR.

CONTENTS

OF THE FIRST VOLUME.



PREFACE.

INTRODUCTION.

PART I.

<i>Of the forms and general properties of Matter ; and of the Agents, or Powers which are concerned in the production of Chemical Phænomena</i>	- - - - -	1
---	-----------	---

CHAPTER I.

Of Attraction	- - - - -	3
---------------	-----------	---

SECTION I.

Cohesion	- - - - -	4
<i>Crystallization</i>	- - - - -	8

SECTION II.

Affinity	- - - - -	22
----------	-----------	----

CHAPTER II.

Of Caloric	- - - - -	65
------------	-----------	----

SECTION I.

Expansion	- - - - -	<i>ib.</i>
-----------	-----------	------------

SECTION II.

Fluidity	- - - - -	79
----------	-----------	----

SECTION III.

Vaporisation	- - - - -	94
--------------	-----------	----

SECTION III.

[illegible]

SECTION IV.

[illegible]

CHAPTER II.

Of the undecomposed inflammable, or acidifiable, unmetallic bases; and of their combinations with the supporters of combustion, and with each other - - - - 270

SECTION I.

[illegible]

SECTION II.

[illegible]

SECTION III.

[illegible]

SECTION IV.

Boron	-	-	-	-	-	-	-	-	364
Fluo-boric acid gas		-	-	-	-	-	-	-	369

SECTION V.

[illegible]

PREFACE.

THE work, which is now offered to the public, was originally intended by the author as a text-book to the lectures delivered by him to the medical students and undergraduates of Harvard University. While arranging the materials, it was thought by him, that by extending it to a greater length, and dilating more upon the general principles of the science, it might still answer the purpose above mentioned, and at the same time be adapted to the class of readers who might wish to acquire a knowledge of the laws of chemistry, without entering much into its practical details.

The excellent work of Dr. Henry, which has hitherto been used as a class-book in the University, is better adapted to the laboratory than the closet. The principles of the science are stated in the most concise manner, and the reader is referred for their demonstration to the results of experiments, with the materials for which, it is taken for granted, he is furnished. As a practical treatise it is admirable, and he who wishes to become an experimental chemist, will, for a time, require no other guide. The deficiency in illustration has indeed, in some measure, been supplied in the editions of professors Silliman and Coxe, and their judicious notes have added much to the value and popularity of the *Elements of Experimental Chemistry*. But there is an inconvenience in a frequent reference to notes, and it is not always easy to accommodate them to the text.

A work which on the one hand shall be more diffuse than that of Dr. Henry, and on the other less extended than the elaborate and profound systems of Drs. Thomson and Murray, will be sufficient to include the most important facts in chemistry, without tasking the memory of the student with a mass of matter, the knowledge of which, though indispensable to the operative chemist, must be uninteresting to the general scholar. The present work was compiled with this view. Such, however, is the immense assemblage of facts embraced by this science, that it has been found necessary in most instances to condense, so far as was practicable, without leaving the subjects obscure. Many important parts may perhaps, from this circumstance, be thought to have been treated of in too superficial a manner. It is hoped, however, that in the most essential points of the science, the facts which have been stated, and the illustrations which have been afforded, will be found adequate to convey a correct idea of the modern doctrines of chemistry.

The question has often been discussed, whether the synthetical or analytical method should be adopted in arrangements for elementary instruction. In a work of this kind a refined and complicated system is not necessary. The plan which has been adopted is simple, and such as appeared to the author the best calculated to present to the reader in a natural order the series of connected facts. In elementary works he believes that it is most expedient to commence with the general principles of the science, and in illustrating the doctrines of chemistry, it is not necessary that the reader should be intimately acquainted with the bodies, by which these doctrines are to be demonstrated. The subjects, therefore, in the following pages have been divided into two parts.

The First Part is devoted to the general laws of the science, and to the properties and modes of action of the Powers or Agents which are concerned in the production of chemical phenomena. In the Second Part are detailed the properties and relations of ponderable bodies, and their compounds. This part is formed into two divisions; in the first is given an account of the properties of *Inorganic* matter; the subject of the second division is *Organic* matter; and Organic matter has been, as usual, subdivided into Vegetable and Animal.

The Natural History of the elementary bodies and their compounds, including Mineralogy and Geology, has been omitted. These subjects, strictly speaking, belong to a different branch of physics, and their classification is founded either upon their external characters, or upon crystalline forms which are to be determined only by the principles of geometry. The excellent work of professor Cleaveland upon this subject is probably in the hands of all those who will open the leaves of these Elements, and the introduction of mineralogy here would therefore be superfluous.

This work is a compilation. It has no pretensions to originality, though from the unsettled state of some parts of the science, there is room for the exercise of the judgement in determining the comparative value of opposing doctrines. It is now submitted with much diffidence to the public, and as it is the first original work of the kind which has been published in the United States, the author indulges the hope, that it will be examined with candour, and its merits determined by liberal criticism.

INTRODUCTION.

THE end of all physical investigation is the knowledge of the nature, properties, and relations of Matter, and of the laws by which its motions are regulated. The different parts of natural science are connected with each other by the identity of their ultimate objects, and the divisions, into which it has been formed, are arbitrary and conventional. Nature herself knows not these distinctions. But the circle of her operations is so extensive that the mind is incapable of grasping the whole, and in order to diminish the labour, and increase the power of acquiring and retaining knowledge, different portions of this circle have been insulated, and certain classes of facts subjected to artificial arrangement. Hence the science of nature has been divided into the three great branches of Natural History, Mechanical Philosophy, and Chemistry.

The province of the Natural Historian is to investigate the structure of the globe, the characters of the beings with which it is covered, and the relations or peculiar properties by which they may be connected, or separated. In one class of beings he discovers an organization susceptible of the powers of life, and an apparatus adapted to loco-motion; in another he sees an arrangement likewise endowed with the properties of vitality, but destitute of the power of voluntary action, while in a third there exist structure without organization, and symmetrical form without animation. His subjects are thus formed into three divisions, and described under the heads of Zoology, Botany, and Mineralogy.

The mechanical philosopher confines himself to the laws which regulate the motions of masses of matter at sensible

distances; he calculates the forces with which they operate, and the effects which they produce, and forms his science from the influence of masses, rather than particles, and from change of place, rather than change of nature.

The laws which govern the actions of the minute or elementary parts of bodies at distances too minute to be recognized by the senses, or calculated by the formulæ of the mathematician, constitute the science of Chemistry. These actions terminate in the production of bodies exhibiting properties differing from those of the particles of which they are composed. The surface of the globe displays a constant succession of motions, and of changes. The forms of matter are continually fluctuating, and the substance which at one period is solid, may exist at another in the form of a liquid, or be resolved into air. The properties of bodies are equally altered with their forms; their particles alternately unite, and recede; if compounded, they are decomposed, and their elements take on new arrangements; if simple, they combine with other matter, and can be no longer identified. Such changes are the subjects of the chemist. It is his duty to observe them and investigate their causes; to determine the nature of bodies, and reduce them to their elements; to ascertain their properties and mutual relations; and to apply the knowledge acquired by observation and experiment to the improvement of the arts, which diminish the wants, multiply the comforts, or administer to the luxuries of social life.

The origin of chemistry, as an art, is unknown, and even the derivation of the term itself, by which the science is now designated, is doubtful.* It is obvious, however, that facts

* "The etymology of the word Chemistry can scarcely be said to have been ascertained. The most plausible guesses are the following: from *χυνω* to melt; *χυμος*, juice; from *kema*, an oriental word signifying black; from *χίμος*, the name of a person eminently skilled in the sciences; from *Chémi*, the Coptick name for Egypt, where the art is supposed to have had its rise.

"According to Bryant, (Ancient Mythol.) it is derived from *Chemia*, and that word from *Cham*." Brande's History of Chemistry.

which daily came within the cognizance of the senses, and which had an important influence upon the continuance or the relations of life, must have early attracted attention, though their observation was not followed by any investigation into their causes or connexions. The ancient arts, which are now known to depend upon chemical action, must have been the results of accidental discovery, or of empirical experiment, and the causes, which in certain circumstances produced glass, or the combination of fibrous matter with the colouring principle of the murex, were probably unknown to the artist who formed vitreous compounds, or dyed with the Tyrian purple.

The name of the science has been supposed by some to have been derived from the Egyptians; and it is not improbable that what little was known upon this subject, might, in conjunction with medicine, have been acquired upon the banks of the Nile. The intimate connexion which subsists between pharmacy and chemistry may perhaps have led the Egyptian priests to cultivate the art of preparing, and compounding medicines; and it has been affirmed, that the artists of this ancient country understood the fabrication of the metals, of glass, and of soap; that they formed many of the commercial salts; and were acquainted with the methods of cutting and polishing stones, of making and painting on enamels, and of dyeing with the assistance of mordants. But even supposing them to have acquired this mechanical knowledge, and there is sufficient reason for believing that they did, it does not appear that they were well skilled in chemistry, or in possession even of a single principle of the science. These arts were apparently unconnected, and they

The Rev. Mr. Palmer, of the University of Cambridge, Eng. has offered the following etymology. Al-chemy, or more properly Al-kemy, *the knowledge of the substance, or composition of bodies*, so named from the substantive (Kiyamon), that is, the substance, or constitution of any thing, from the root (Kama.) See Golius' Lexicon. Thomson's Chemistry, vol. i. p. 4. 5th ed.

who cultivated them succeeded by chance, or were learned by accident.

The sciences of calculation were cultivated with more success than those of chemistry and medicine, and this remarkable people have left sufficient proofs of their progress in astronomy, geometry, and mechanics. Astrology, and magic constituted a part of the study of the Egyptian priests, and it is affirmed by Diodorus Siculus that they taught these occult sciences to the Chaldeans. Their ideas upon these subjects were concealed under symbolical characters which were inscribed by Hermes, the minister of Osiris, upon tables of stone. The art of transmutation has been supposed to be veiled by these hieroglyphics, and hence alchemy has sometimes been called the Hermetic art.

The lofty and imposing philosophy of Greece was not favourable to the developement of truth by patient observation or laborious experiment. The dogmatic systems of the Ionic and other schools, in which sublime ideas in morals were mingled with absurd or extravagant notions of matter, while they disciplined the mind to virtue, led it astray from physical truth. "To generalize upon the great forms or powers of nature, as elements, requires only very superficial observation;" and the physics of the Grecian sages have nothing in them to attract attention, but the dignity of their subjects, and the boldness of the imagination which could reach them. The sensible elements of Thales, the unity of Parmenides, the ideas of Plato, the first matter of Aristotle, and the numbers of Pythagoras, convey to the mind nothing distinct, nothing of which we find the prototype in nature; and we feel regret that men who were capable of arriving at the knowledge of the sublimest moral truths, should have been misled by false methods of reasoning, and a desire to form a system of physics. Of all the doctrines of the ancients, respecting the essence or constitution of matter, there is but one which seems likely to be revived by the moderns. In the philosophy of Epicurus may be found the rudiments of the theory of

atoms. He taught that all bodies consisted of minute parts, simple principles, or atoms, which were immutable, indivisible, and indestructible ; that they possessed gravity, and gave rise to motion ; and that they differed from each other in magnitude, figure, and weight.

The first distinct traces of chemistry may be found in the writings of the Arabian physicians ; and it is remarkable that the same nation, which, when first armed with the sword of Mahomet, was equally fatal to the lives and records of the unbelievers, should itself have cultivated the sciences which it had condemned, and have preserved the germ of knowledge that was destined to extend its branches over all Europe. It is equally remarkable that the spirit of philosophic observation which characterized that sagacious people, should have been so soon extinguished, that science, like the sun, should have travelled westward, and Arabia have been overshadowed with ignorance, and her efforts in science palsied by superstition. The works of Rhazes and Albucasis, of Geber and Mezué, though obscured by the mysterious language of alchemy, and filled with allusions to the art of transmutation, show that they were acquainted with many chemical operations, with some of the active compounds, and with different kinds of apparatus. The names still applied to several important instruments and chemical substances, sufficiently point out their Arabian origin, and remain to convince us that some credit is due from posterity to the philosophical spirit of the descendants of the prophet.

From this nation, also, it is supposed arose those singular delusions, which, for some centuries, occasioned a deep interest to be taken in the products of European laboratories. Ignorant of the nature of bodies, unaccustomed to the effects of their mutual action, and unsatisfied by the substantial, but gradual benefits, which spring from a patient and laborious experimental investigation, they conceived that the baser metals might be transmuted into gold, and all the efforts of the art were directed to the discovery of the philosopher's

stone. They had also seen enough of the protean nature of chemistry to excite the imagination, and to indulge the most extravagant hopes, and their labours were lightened by the belief that they might terminate in the formation of a liquid, which should renovate the frame when impaired by age, or exhausted by disease. With the elixir of life, and the philosopher's stone, with immortal youth, and power, and wealth, the alchemist need not look to a future existence for pleasures which he was not certain to obtain, nor for rewards which he was not sure that he deserved. The alkahest or universal solvent constituted another subject of profound research, and these men busied themselves in attempts to procure a substance, which, even if obtained, could not have been preserved.

These notions, which were cherished by the romantic imaginations of the Arábians, were infused during the crusades into the bosoms of the Europeans. The ardour of religion, as has been justly observed, disposed the christian warriors rather to believe than to reason ; and the same enthusiasm of character which led the paladin to the tomb of the Saviour, and to fight the battles of the righteous, prepared him to adopt the magnificent hopes of the infidel. These hopes were indulged with the more ardour from the circumstance, that many of those who passed into Palestine had exhausted their wealth in furnishing themselves and their dependants for the holy war, and had no other temporal reward to expect, than the title of champions of religion. The delusions of alchemy were thus transferred from Asia to Europe. The transmutation of metals was soon reduced to an art, and those who professed to be most deeply skilled in its operations, assumed the name of adepts, invented a symbolical language which none but they could understand, or were willing to acquire, and cheated others of their wealth by the display of magic, and the results of treacherous experiment. So extensive was the evil produced by the alchemists, that it attracted the attention of the sovereigns of Europe. John XXII, who

ascended the papal throne in 1360, issued an edict against them, setting forth that “they promise what they do not perform;” and in the fifth year of the reign of Henry IV, the Parliament of England prohibited attempts at transmutation under pain of punishment.

The most distinguished among the alchemists was Paracelsus, a native of Basle in Switzerland. This singular man possessed a bold and original mind, which, when loosened from the restraints of the schools, and the influence of ancient authority, knew not how to direct its views, or limit its operations. He was the first public lecturer on chemistry in Europe, and this station, together with the reputation which he acquired by the application of chemical medicines to the cure of diseases, afforded him the opportunity of attacking, and of prostrating the dogmatic school of Galen. But the merit of completing this conquest over ancient opinion must be shared with Vesalius, who pointed out the errors of Galen in Anatomy, while Paracelsus was employed in ridiculing his medicines. In the character of this alchemist were combined the extremes of arrogance and meanness, of the freedom of truth, with the boldness of pretension, and of enthusiasm of mind, with depravity of morals. It appears by the works which he left, that he openly laid claim to monarchy in medicine, that he dealt in the mysteries of magic and astrology, and pretended to have discovered the elixir of life, and the philosopher’s stone; but the latter could not raise him above poverty, nor the former prevent him from decay, for, exhausted by disease, “he terminated a life, stained with every vice, and deficient in every virtue, in the year 1541, at an obscure inn at Saltzburg, in Bavaria.”

In reflecting upon the influence which the pursuit of alchemy had upon physical investigation, it must be acknowledged to be greater than, at first view, would have been imagined. It diverted the mind from the study of words, to the examination of things; and as experiments on the nature and relations of bodies were at that period altogether novel, it can hardly be

supposed, that however absurd and impracticable the specific objects of the alchemist might have been, he should not have arrived during his researches at new results, unexpected discoveries, and useful facts. Though their works can neither amuse, nor enlighten the reader, yet Basil Valentine described the properties of antimony; he employed the mineral acids, and is supposed to have been the discoverer of ether. Paracelsus will descend to posterity as the first who introduced the preparations of mercury into medicine, and rendered physicians more conversant with the medicinal qualities of opium. Libavius described many chemical compounds; and Van Helmont, who appears to have had a glimpse of true philosophy, was acquainted with more than one gaseous fluid, and with the elasticity of the air, which he applied as a measurer of heat.

But as the enthusiasm of mind, which originated in religion, and terminated in the desire for temporal power and pleasure, became weakened; as men began to reason before they believed, and substituted demonstration for faith, the reputation of alchemy gradually declined. The poverty of those who professed the art forced the conviction, even upon the most credulous, that it was the offspring of ignorance, and was supported by knavery, and by the middle of the seventeenth century, it existed only in history.

This dark period, however, must not be passed over without noticing one of the very few men who rose above the age in which they lived, and investigated nature with the spirit of true philosophy. The works of Roger Bacon, who flourished in the thirteenth century, distinguish him as one, who sought for physical truth with zeal and industry, and whose labours were rewarded with success. He is said to have discovered the mode by which gun-powder could be formed, and the uses to which it might be applied; his inventions were so numerous and wonderful, that his cotemporaries, instigated by the evil spirit of ignorance or envy, accused him of employing magical influence; and it is probable, that the enigmatical style of

his writings was assumed to shield him from the dangerous reputation of superior knowledge and sagacity. Towards the commencement of the sixteenth century, the Germans had made some progress in the knowledge of minerals, and the work of the learned George Agricola, which was published in 1542, *de Re Metallica*, contained much practical information.

Chemistry, in common with the other physical sciences, owes an immense debt of gratitude to Lord Bacon. When exiled from court, he devoted himself to study, and in the shades of retirement employed the powers of his great mind in pointing out to his cotemporaries, and to posterity, the only true method by which knowledge was to be acquired. He enumerated the causes, under the name of *Idola*, by which error in the pursuit of knowledge had been perpetuated, and attributed the superficial and imperfect systems of physics then known, not to any irregularity or confusion in the operations of nature herself, but to the hasty assumption of general propositions or principles, which were taken as data for disputation or argument. He taught that man was the servant and interpreter of nature, and could acquire physical knowledge only by observing and imitating her operations; that the mind in its pursuit was to be assisted by the senses, and by the use of instruments, by which the properties and relations of objects might be examined, that facts must be accumulated, and generalizations slowly formed, proceeding from particulars, to those which were more general, and from the last to others still more comprehensive, until by a series of inductions, it arrived at length to a universal principle or theory. The period at which the *Novum Organon Scientiarum* appeared was peculiarly favourable to the adoption of the inductive method, which it inculcated. The illusions of alchemy, if not altogether dissipated, were receding from view, the reality of magical and astrological influence was at least doubted, and the follies of the dialectic school were passing away. The mind, thus freed from error, was prepared for truth, and the philosophy of Bacon, like the beacon to the

mariner, while it pointed out the rocks and quicksands of the former, directed her to the peaceful bosom of the latter.

The influence of the inductive method, and its superiority over all other systems which had been invented, were soon perceived. It was found that little or nothing was known of the materials of which our globe is constituted, or of the laws by which their motions are regulated; the natural sciences were to be created, the facts upon which they were to be founded had not yet been collected, and the attention of the philosopher was to be directed, rather to the phenomena of nature, and the mutual action of the elements of matter, than to the formation of principles, or the enunciation of theories. Hence, observation was substituted for conjecture, and experiment for disputation, the discovery of one fact necessarily led to that of another, and thus was laid on the bosom of nature the firm foundation, upon which has since been raised the temple of physical science. Lord Bacon died in the year 1626, and the middle of the seventeenth century may be considered as the period at which the mind, so long misguided by false methods of reasoning, and oppressed by the weight of system and ancient opinion, returned to the right path, and sought for knowledge in observation and experiment. Learned Societies were founded, and zeal in the cause, and success in the pursuit of truth, were promoted by an union of efforts. Florence, the city of the Medici, set the example in 1651, and the publications of the *Academy del Cimento*, which leave us nothing to regret, but that they were so small in number, are honourable proofs of the industry of its members, and the usefulness of the Institution. The *Royal Society* of London, which was formed in 1645, and incorporated in 1662, could boast of Slare, of Boyle, and of Hooke; it still exists, and the *Philosophical Transactions* constitute an invaluable offering of its distinguished members to physical science. The French *Academy of Sciences* was established in 1666, and under the genial reign of Lewis XIV, men of learning and of science became the pensioners of the monarch, and repaid him by

diffusing a knowledge of nature and the arts among his subjects. This society, under different names, has been continued to the present day, and the Institute of France is equal in fame and in utility to the Royal Society of Britain. The *Academia Naturæ Curiosum* of Germany, and the *Bolognian Institute*, were founded upon the same principles, they pursued the same paths, and reaped the same rewards.

The first impulse appeared to be directed towards the investigation of the subjects which now constitute Mechanical philosophy, or General physics. The invention of instruments for philosophical research rapidly succeeded each other, and the barometer of Torricelli, the air-pump of Guericke and Boyle, and the thermometer of the Florentine Academy, facilitated in a wonderful degree the progress in the knowledge of the properties of the air, and the important relations of heat. No branch of physics was cultivated with more zeal and more success than Astronomy. The system of Copernicus which was revived and established by Gallileo, in defiance of religious bigotry and papal power, finished the work which had been commenced by the alchemists and the empirics, and destroyed forever the influence which the philosophy of the ancients had so long exerted upon the mind. Men who were now relieved from the necessity of believing, began to observe and to reason, and the result of freedom of inquiry was the conviction, that no system could be stable, which was not founded upon observation and experiment, and no theory permanent, which was not derived from successive inductions. The discoveries of Kepler and Gallileo, of Huyghens and Descartes, of Gassendi, Cassini, and the great Newton, irresistibly attracted the attention of inquiring minds by their novelty, and retained it by their grandeur. During this period, however, chemistry was making a slow but sure progress. Glauber, a chemist of Amsterdam, deserves honourable notice as the discoverer of several saline compounds, and of the production of vinegar by the distillation of wood. In this century, also, were published the works of

Boyle, Hooke, and Mayow. Hooke, in his *Micrographia*, gave a theory of combustion, which was unaccountably overlooked until more than a century after, when posterity was willing to do justice to its merits. He also showed that the structure of crystals might be explained upon the supposition, that their elementary atoms, or particles were spheres; his hypothesis, however, was imperfect, but it has lately assumed the form of a theory by the labours of Dr. Wollaston and Mr. Daniell. Mayow amplified the views of Hooke respecting the nature of combustion, and wrote a treatise upon the mutual actions of different bodies, which discovered much knowledge of chemical affinity. Chemistry was likewise successfully cultivated in France, and the labours of Homborg, Geoffroy, and the two Lemerys, unfolded the properties and relations of a multitude of bodies.

But as yet, chemistry had no distinct character, its parts were connected by no general principle, and it offered no claim to be considered as a separate science. It was reserved for Newton to give it this character, and to entitle it to claim this rank. He inferred that the motions of the particles of bodies which produced chemical phenomena were owing to the attractions which took place between them, that their combinations were rapid in proportion to the force with which that power operated, and that when a compound of two bodies was decomposed by a third, it was in consequence of the superior attraction of the latter for one of the former. Whether Geoffroy adopted this idea from Newton is uncertain, but not long afterwards he established its truth in his tables of affinity, founded upon the relative attractions of different bodies.

The period had at length arrived when the nature and properties of a great number of chemical bodies were accurately known, when the processes of the laboratory were refined by experience, and conducted with much manual dexterity, and when the operator was satisfied to be useful, without being great, and to be learned, without being in possession of the philosopher's stone.

Notwithstanding Newton had happily applied the principle of attraction to account for the motions of the particles of bodies, and had given to chemistry the rank of a science, some connecting principle was still wanting to establish the relations of bodies, and to serve as the basis of a regular arrangement. No general theory of chemistry had yet been formed; it consisted of insulated facts, and independent observations. This theory was developed by the researches which were made into the phenomena of *Combustion*.

The way was led by Becher, who was born at Spires in 1645, and died in England in 1685, and who, with a mind of strong powers, was possessed of much practical skill and knowledge. He conceived the idea, that there existed in nature but one elementary matter, which was earth, and of which there were three modifications, viz. the vitrifiable, the metallic, and the inflammable. By the combination of these species in various proportions was produced, as he supposed, the variety of forms of matter which are found in nature. But this great abstraction partook too much of the character of the ancient philosophy; it was the work rather of the imagination, than the judgment, and though it might amuse, it could not instruct. Ernest Stahl, who was born at Anspach, in Franconia, in 1660, and was the disciple of Becher, possessed, with a greater knowledge of chemistry, a more correct and disciplined mind than his master; and by aiming at less than so universal a generalization, succeeded in forming a theory, which will be noticed so long as the science itself is cultivated. Stahl inferred that there existed in all inflammable bodies a common matter, which might be considered as the cause of their combustibility. This matter, which was considered as more subtile and attenuated than the earth of Becher, and highly elastic, he called *Phlogiston*. He assumed that while bodies were burning, the phlogiston was in the act of disengagement; that when consumed, the bodies were burnt, and incapable of going through the same process a second time; that the heat and light observed in combus-

tion, were the results of the violent motions of the phlogiston, as it escaped from the inflamed body; and that phlogiston might be slowly disengaged without the usual phenomena of fire, or might be silently transferred from one body to another, the former losing and the latter acquiring the property of inflammability. Such was the simple and elegant theory of the German chemist, and its merit depends less upon its application to combustion, than upon its involving a general principle, as stated in two last propositions. The works of Stahl were published between the years 1723 and 1732, and his hypothesis of combustion was no sooner known, than it was embraced with zeal, and disseminated with wonderful rapidity.

This theory was arranged with so much skill, it was supported by so many facts, and accommodated with so much ingenuity to all that was then known of chemistry, that it attracted universal attention, and was soon adopted as the foundation of the science.

Under the auspices of this doctrine, which lost none of its popularity for half a century, chemistry acquired a specific character, many of the substances which are now ranked among the elements were discovered, the properties of an immense number of compounds were accurately determined, the instruments of research were greatly improved, and the operations of the laboratory were conducted with comparative ease, precision, and simplicity. Among those who were contemporary with Stahl, the learned Boerhaave holds a conspicuous place. The physician and the chemist may dwell with pleasure upon the character of this good man, for he belongs to both. He was born in 1668, and died in 1738. By his powers of mind, his knowledge, and experience, he rendered the University of Leyden, the great medical school of Europe; his piety was equal to his learning, and his humanity not inferior to his skill. Possessing a truly philosophical mind, he saw and expatiated upon the necessity and the advantage of observation and experiment in all investigations for the

discovery of physical truths ; and clearly unfolded the errors which resulted from premature induction, and the establishment of systems. His *Institutes of Medicine* are read to this day with pleasure, if not with profit, and his *Elements of Chemistry* contain all that was then known on that subject. He was a benefactor to both sciences, and his name will descend to posterity as one, who, though devoted to the severer studies, never forgot that he was a man, and though exalted in fame, never ceased to feel the charities of life.

At this period, the airs or elastic fluids, with the exception of the atmosphere, were not known to exist. Notwithstanding the sagacious observations of Hooke, and of Mayow, which, if properly followed up, would have carried back the era of 1772-80, to the latter part of the seventeenth century, this interesting branch of chemistry was altogether overlooked, and the discovery of the gases was reserved for a more fortunate period of the science. Van Helmont, a century before, seems to have had some notion that there were different species of elastic fluids, and from him was received the generic term *gas*, by which this class of bodies is now distinguished.

The merit of having first directed the attention of chemists to this important branch of inquiry is generally bestowed upon the Rev. Dr. Hales of Great Britain, who published his researches into vegetable physiology, under the name of *Statistical Essays*, in 1726-7. He performed a great variety of curious and interesting experiments upon the moisture absorbed and perspired by plants, the force and motion of the sap, and the quantity of air inspired. In his *chymio-statical* experiments he endeavoured to show, that a quantity of air was “wrought” into the composition of vegetable and animal substances, and that it might be obtained from them in the elastic state during their decomposition. At every step in this investigation, he appears upon the point of making discoveries which would have conferred upon him lasting fame ; but prepossessed with the idea, that all the airs he obtained were essentially the same, though disguised with various effluvia, he neglected to

put them to the test of experiment, and thus lost the opportunity of perpetuating his own reputation, and of materially accelerating the progress of chemistry.

The honour of having first established *Pneumatic Chemistry* belongs to Dr. Black of Edinburgh. The cause of the causticity acquired by the alkalies, and by lime-stone, or marble when exposed to heat, had been a subject of much discussion among chemists, and no satisfactory solution of the phænomenon had been offered. The substance called *Magnesia*, the basis of Epsom salts, and which had been recently discovered, attracted the attention of Dr. Black; he submitted it to experiment, and obtained from it an elastic fluid, the properties of which he found to be very different from those of atmospheric air; it was therefore considered by him as a new species, and named *Fixed air*. The same substance he afterwards found to exist in a solid state in marble, and the mild alkalies, and to render their bases inert. When exposed to heat, fixed air was evolved, and the bodies then became caustic. These discoveries were published in the year 1754, in his inaugural dissertation *De Magnesia Alba*. They were the first labours of this celebrated man. In his posthumous works, or Lectures, is unfolded the doctrine of heat, which has proved the source of incalculable benefit to society. The qualities of his mind were admirably adapted to physical pursuits. Clear and methodical, his experiments were always simple in contrivance, adequate to the purpose, and perfectly convincing in their results; they are detailed in a style, remarkable for its simplicity and perspicuity, and his Lectures present a specimen of pure inductive reasoning. He made but few discoveries, but they were all great, and the practical advantages which flowed from them have proved them to be equally useful.

Cotemporary with Dr. Black was Mr. Cavendish, who, though of high rank, and possessed of a splendid fortune, devoted his life to the cultivation of science. He has been characterized by Sir Humphry Davy as one, who “carried

into his chemical researches a delicacy and precision which have never been exceeded ; possessing depth and extent of mathematical knowledge, he reasoned with the caution of a geometer upon the results of his experiments ; and it may be said of him, what perhaps can scarcely be said of any other person, that whatever he accomplished was perfect at the moment of its production. His processes were all of a finished nature ; executed by the hand of a master, they required no correction ; the accuracy and beauty of his earliest labours even, have remained unimpaired amidst the progress of discovery, and their merits have been illustrated by discussion, and exalted by time." Mr. Cavendish pursued the track of Dr. Black. He discovered the nature, and demonstrated the properties of hydrogen gas, or inflammable air ; he analyzed with precision atmospheric air, showed the exact proportions of its constituent parts, and ascertained the fact that they are always the same ; he proved by direct synthetical experiments the composition of *nitric acid*, and made the brilliant discovery of the compound nature of water.

At this period, also, Sweden became distinguished in the annals of chemistry. The labours of the illustrious Bergman added in an eminent degree to the stock of knowledge respecting affinity, and the composition and analysis of mineral waters ; he laid the foundation of the more recent theory of crystallography, and by his industry and success gave a new impulse to chemical investigations.

It was not the least of his merits that he perceived and fostered the rising genius of Scheele. Born in an humble station of life, this admirable man rose by his own industry and powers of mind to the highest rank among the chemists. Engaged at an early period of his life in the study of the science, he devoted to it all his thoughts, and may be said to have lived in his laboratory. "Scheele possessed in the highest degree the faculty of invention ; all his labours were instituted with an object in view, and after happy or bold analogies.—With very small means, he accomplished very

great things. No difficulties deterred him from submitting his ideas to the test of experiment.—He was eminently endowed with that candour which is characteristic of great minds, and which induces them to rejoice as well in the detection of their own errors, as in the discovery of truth.”* The labours of this great chemist were immense. Though he died at the early age of 44 years, he made more discoveries, and brought to light a greater number of important facts, than any chemist of a former, and perhaps also of a succeeding age. He first pointed out the nature of manganese; he obtained and demonstrated the nature of oxy-muriatic gas, or chlorine; developed the properties of barytes, and was the discoverer of oxygen and azote. The knowledge of the nature of tungsten, of molybdena, prussian blue, and a number of the important vegetable acids, we also owe to his sagacity. Besides all these, his *Treatise on Fire and Air* contains most of the important facts which are now known on the subject of *Radiant Heat*, and the chemical action of light; and the details of the experiments by which he arrived at the discovery, both of *Empyrean air*, or oxygen gas, and of *Foul air*, or azote.

While Scheele, like the Aurora Borealis, was illuminating with his genius the regions of the north, Dr. Priestley was pursuing his brilliant career in England. The inquiring mind of this distinguished philosopher was always directed towards the discovery of truth. He possessed, in an eminent degree, the qualities which might be loved, and though persecuted by his countrymen for his theological opinions, the attachment of his friends followed him in his exile, and his memory is still cherished with the warmth of affection. In his physical writings, he is distinguished by his candour and simplicity, and if his theories were proved erroneous, they were relinquished without effort. Upon the great question of the existence of phlogiston, his opinions were settled, and the last effort of his mind was in its favour. With an apparatus of the simplest kind, Dr. Priestley made more discoveries in

* Davy.

pneumatic chemistry than any preceding experimenter. The demonstration of the properties of oxygen gas, which was first obtained by him in August 1774, was alone sufficient to render his name immortal. It is a curious circumstance, however, that he, who was so devoted to the theory of phlogiston, should have been the one to furnish its opponents with the substance, by which its doctrines were to be falsified, and even its name to be expunged from chemical philosophy. By the invention of a simple but convenient apparatus, the *water-trough*, or *hydro-pneumatic apparatus*, and by the use of quicksilver, he was enabled to collect and preserve sufficient quantities of different airs, to ascertain their nature, and determine their properties; and besides oxygen gas, he is to be considered as the discoverer of *sulphurous acid*, *fluoric acid*, *muriatic acid*, *carburetted hydrogen*, *carbonic oxide*, and *ammoniacal gases*. He first applied electricity as an active power to chemistry, and performed a multitude of ingenious and important experiments to support the doctrine of phlogiston.

This doctrine was still in vogue, and the processes of combustion, as well indeed as the whole of philosophical chemistry, were still explained in conformity with the principles of Stahl. But the period of rigid chemistry had at length arrived when inquiring minds were to be satisfied only by demonstration. It was perceived that the existence of phlogiston was problematical, and that the belief in its reality was continued, rather from the ease with which it enabled chemists to explain the phenomena of the science, than from any precise knowledge of its nature, or any actual experience of its properties. The foundation of this doctrine, therefore, was hypothetical, and in framing it facts had been overlooked, which were opposed to its conclusions, and incompatible with its laws. The influence and the absorption of air in combustible processes, which had been long before noticed by Hooke and Mayow, were disregarded, and no attention had been given to the facts published in 1650 by John Rey, a French physician: although the experiments which he detailed de-

monstrated, in the most satisfactory manner, the increase of weight resulting from the combustion or calcination of the metals, and the cause upon which it was dependent. It is difficult to conceive that a practical chemist, like Stahl, should have been ignorant of facts like these ; but as they were adverse to his hypothesis, they might have been either studiously avoided, or passed by as circumstances of little importance.

The gradual progress of chemistry, the number of new facts almost daily brought to light, the discovery of the elastic fluids, and I may add the application of sound and rigid principles of reasoning, opened to the chemist more correct and extensive views of the science, and developed in a clearer manner the mutual relations of bodies. The knowledge which Dr. Black disseminated of the properties of heat, and the demonstration of those of oxygen by Dr. Priestley, prepared the way for a total revolution of opinion, and a system at once imposing and beautiful was erected upon the ruins of the German theory of phlogiston.

To France belongs the honour of having given to chemistry a new form, and another language. In 1772, M Lavoisier began to turn his attention to the phænomena of combustion, and in 1777 completed the theory which has rendered his name immortal. No man of his age was better qualified to form and diffuse the principles of a novel system. He was respected in public, and beloved in private. His hours were devoted to science and his country. To the latter he was a faithful servant, and to the former an exalted benefactor. But neither his knowledge, nor his patriotism, nor his private virtues, could preserve his life. It was his misfortune, and the misfortune of science, that he lived in the savage age of the French Revolution. "He was rich, and therefore criminal ; virtuous, and consequently offensive. In short, because his public character and private life were equally blameless and unimpeachable, he was marked out for destruction, and murdered upon the scaffold on the 8th of May 1794, in his native city of Paris, in the 51st year of his

age.”* It has been said that he requested a short respite to enable him to complete some experimental investigation which had been commenced, but he was denied, and hurried with inexorable cruelty to his fate.

The theory of this distinguished man involves the principles not only of combustion, but of the whole science of chemistry. The two leading facts were furnished by Black and Priestley, the combinations and deductions were his his own. This doctrine is as follows.

1. That combustion will not go on without the presence of oxygen.

2. That in every case of combustion this air disappears, the burning body increases in weight, and the weights lost by the one, and gained by the other, are precisely equal. Combustion, therefore, is the act of union of oxygen with the inflammable body.

3. That the heat and light which are manifested in this process, and which are inferred to have been previously combined with the oxygen gas, are given out in consequence of the greater attraction of the ponderable basis of the oxygen for the matter of the combustible body.

4. That oxygen may be slowly and silently transferred from one body to another, without the usual phenomena of combustion ; and

5. That oxygen is the principle of acidity.

This theory, then, which Lavoisier was some years in forming, and which he distinctly claimed as his own, was founded upon the phenomena exhibited by oxygen in its combination with other bodies. It was the result of a long and laborious investigation, of profound research, and of slow and cautious induction. It has been of incalculable advantage to chemistry, and places its author in the highest rank of philosophers.

But the system was not yet completed. The language of the science was derived partly from the Arabic, and in part

* Mr. Brande.

from the more fantastic, and barbarous phraseology of the alchemists. The entire change, or at least the reform of nomenclature was absolutely necessary, and the period chosen for the alteration was peculiarly favourable to its diffusion and adoption. The labour of preparing it was undertaken by Lavoisier, and in conjunction with M. M. Morveau, Fourcroy, and Berthollet, he published, in the year 1786, a new nomenclature founded upon the combinations of oxygen, and the radicals of which were derived from the language of the Greeks. From that time the reputation of French philosophy was identified with the new system, and by methods equally judicious and ingenious, it gradually became the only language of chemistry.

It was some time, however, before this system was universally established. Mr. Cavendish still adhered to the doctrine of phlogiston, and even published a valuable paper in its favour; Dr. Priestley laboured with zeal in its cause; and Mr. Kirwan took the field against Lavoisier in his *Essay on phlogiston, and the constitution of the acids*. But France at that period was fortunate in her chemists; the fame of Lavoisier, of Morveau, of Berthollet, and of Fourcroy, was firmly established, and the work of Mr. Kirwan was so completely refuted by them, that its author, with a candour which cannot be too much admired, renounced his opinions in favour of phlogiston.

From this period chemistry assumed the character of an exact, beautiful, and useful science. The impulse given to it by the labours of the French chemists accelerated its progress with wonderful rapidity. New and interesting bodies were discovered; the properties of others which were already known were examined with more skill, and determined with more care; the introduction of weights and measures gave precision to the operations of the laboratory; and the connexion between chemistry and the arts was clearly established.

The period between the years 1780 and 1800 was prolific in eminent chemists; but the labours of Klaproth, Bucholz,

Richter, Gehlen, and Trommsdorf in Germany ; of Gren, Gadolin, Hielm, and Ekeberg in Sweden ; of Brugnatelli in Italy, and of Crawford, Irvine, Hope, and Henry in Britain, although honourable to themselves, and useful to the science, must unwillingly be passed over in silence.

A new era commenced with the nineteenth century, and the chemist must always dwell with pleasure upon this period in the history of his science.

During the last eight years of the preceding century, the attention of the philosophical world had been fixed on the discovery of Galvani of Bologna, that there existed in the animal body a principle analogous to, if not identical with, electricity ; that by a peculiar but simple arrangement, this power might be put in operation, and that during its passage from one part of the muscular apparatus to another, it acted upon the irritable fibre, and produced contraction. This hypothesis was adopted, and illustrated by experiment ; but it was afterwards shown by Volta that Galvani reasoned erroneously from facts, and that the muscular contractions were the consequence, not of any power inherent in the animal fibre, and equalized by a conductor of electricity, but simply of the contact of two dissimilar metallic bodies, the living animal matter introduced into the arrangement merely operating, by its irritability, to render evident the small quantity of electricity evolved from such combinations. The great discovery of Volta, which took place about the year 1800, of a mode of accumulating this power of *Galvanism*, as it had been called, independently of the animal system, while it destroyed the hypothesis of the Bolognian philosopher, gave to the chemist an agent unequalled in the variety, the extent, and the energy of its action upon common matter. The operation of the pile of Volta, its effects, and the theory of its power, immediately became the subjects of research, and a field rich in discovery, and fruitful in knowledge, was opened to the chemist.

At this period commenced the career of Sir Humphry Davy. While superintendant of the Pneumatic Institution. es-

tablished by Dr. Beddoes at Bristol, he made his hazardous experiments upon the respiration of the different gases, and the work upon this subject which was published in 1800, and which contains the result of much deep and successful research into the combinations of Oxygen and Nitrogen, first gave him rank among the chemists. The situation of lecturer at the Royal Institution of London opened a wider field for the display of his powers, and Voltaic electricity offered the first subject for the exercise of a mind, trained to industry, rapid in thought, and fertile in invention. It was there that he studied the modes of action of electricity, varied its combinations, established the general facts which constituted the basis of his theory of its operation, and pursued it with so much zeal, and was rewarded with such success, that it was considered as a branch of philosophy peculiarly his own. In 1807 a discovery was made by him which would have transmitted the name of any one to posterity. The fixed alkalies, *potash* and *soda*, had, until this time, been considered as simple substances; the phænomena which they exhibited, and their modes of combination, it is true, favoured the opinion of their compound nature, and conjecture supplying the place of knowledge, singular ideas respecting their elements had been expressed. The voltaic experiments of Sir H. Davy, in affording the knowledge of their real constitution, dissipated these wild notions, proved that they were compounds of oxygen with metallic bases, and furnished the first important fact against the theory of Lavoisier, that oxygen was to be considered merely as the principle of acidity.

The demonstration of the composition of the alkalies was important in every point of view; it brought to light bases possessed of singular properties; it gave to chemists agents of great activity in the analyses of other compounded matter; it led directly to the discovery of an analogous constitution in the alkaline earths; reduced the classes of the elementary bodies, and served to establish very important analogies between the different chemical substances.

It was in fact, while employing the voltaic battery that Sir H. Davy was induced to doubt the theory of the compound nature of oxy-muriatic acid.

When the existence, the properties, and the modes of combination of oxygen had been established, M. Berthollet, one of the most learned and distinguished of the French chemists, turned his attention to the *dephlogisticated marine acid* of Scheele ; he studied its mode of formation, investigated the phenomena which it exhibited with other substances, and not only resolved it into its elements, but even stated the proportions in which they were combined. These researches, which conferred an important benefit upon society by the introduction of a powerful agent into the art of bleaching, terminated in the establishment of the theory, that oxy-muriatic acid was not muriatic acid deprived of phlogiston, but that substance combined with oxygen, and that contrary to the opinion of Scheele, muriatic acid was to be considered as a simple body, and oxy-muriatic acid as a compound ; a theory, which was supported by experiments so convincing, and reasoning so satisfactory, that it received unlimited credit. In 1809, M. M. Gay-Lussac and Thenard showed that the original hypothesis of Scheele might be supported, but it was not pursued by them, and it remained unprosecuted until it attracted the attention of Sir H. Davy. In 1810, the detail of experiments which had been made for the purpose of deciding the nature of the yellow-coloured gas obtained by the Swedish chemist was read to the Royal Institution ; and the conclusions were drawn, that it was a simple body, analogous in its general properties to oxygen, that it combined with hydrogen to form muriatic acid, and with the inflammable bases constituting binary compounds ; that it was to be considered as a supporter of combustion ; and that neither the gas itself, nor its compounds gave off oxygen, unless water were present. To this substance was given the name of *Chlorine*. This view of chlorine, opposed as it was to established opinions, and more directly to the theory of Lavoisier, has been

gradually gaining ground, it has been adopted by M. Berthollet, and is now believed by a great majority of European chemists.

The discovery of the important substance which has been named *Iodine*, and which bears a striking analogy to chlorine in some of its properties, took place soon after the enunciation of this theory, and confirmed its doctrines. Sir H. Davy was one of the earliest investigators into this subject, and the merit of having determined its properties and relations must be shared between him, and M. Gay-Lussac.

The late researches of this philosopher are inferior, neither in importance, usefulness, nor beauty, to those which have been already mentioned.

It is well known, that an inflammable air, which is a compound of the two elements, carbon and hydrogen, and which is familiar in Great Britain by the name of *fire-damp*, accumulates in coal mines, and when fired produces explosions, destructive to the works, and to the lives of the miners. It was the dictate equally of interest and of humanity, to introduce a mode of illumination, which, while it enabled the workman to pursue his solitary labour with ease, might at the same time give to him the consciousness of security. Such, however, were the peculiar difficulties connected with this object, that no effectual means of obviating the danger was discovered, until Sir H. Davy directed his attention to the nature and properties of fire-damp, and explosive mixtures. The results of his researches terminated in the discovery of one of the most extraordinary and beautiful of the principles of chemistry, and the *safety-lamp* constructed upon this principle displays, in the most unequivocal manner, the triumph of science, and the happy effects which proceed from the direct application of its laws to the improvement of the arts of life. No invention, not even that of the steam-engine, can claim a more direct relation to philosophy; the neatness and simplicity of its construction render it equally convenient and at command, it will probably annually preserve to his country

many valuable lives, and the consciousness of having succeeded in this great and humane design, and of having merited the gratitude of his fellow-beings, must excite in the mind of its author feelings, infinitely superior to those which could result from the extrinsic reward of wealth, or rank, or power.

Although the phænomena of combustion, as has already been stated, attracted much of the attention of philosophical men, from the first dawn of theoretical chemistry, and were made the subjects of much research, experiment, and reasoning, the nature of *flame* was little investigated, and less understood. Chemists appear to have been satisfied with the opinion, that it consisted of light and heat, and the theory being settled, it remained only to believe. Within a short period, however, this part of combustion has been examined by Sir H. Davy; his experiments have already developed many curious and interesting facts, and when the subject shall have been completely unfolded, the principles deduced from them will have an important influence, not only upon the theory of this process, but probably upon the general doctrines of the science.

It is to be remarked, that all the labours and discoveries of Sir Humphry Davy are immediately connected with the great theoretical questions in chemistry. Even his first efforts were made to strengthen the hypothesis of Bacon, of the nature of *Heat*. His investigations into the action of *Electricity* terminated in a theory as bold as it was novel; the discovery of *Potassium* and *Sodium*, or the bases of the Fixed alkalies, first demonstrated that oxygen was not to be regarded as the principle of acidity alone; the experiments and conclusions relating to the nature of *Chlorine* and *Iodine* restricted the doctrines of Lavoisier within narrower limits; and his views of the composition of acids, and neutro-saline compounds, of the constitution and the phænomena of flame, and of the analogies of the simple or undecomposed bodies, must have the effect to weaken still more the confidence in the universality of the French system.

From the time that the doctrines and nomenclature of Lavoisier were firmly established, Paris became the focus of chemical philosophy. Her chemists took the lead, and for a long period were without rivals. Though they were dispersed during the first convulsions of the Revolution, which shook the foundations of civil society, their pursuits were found to be too intimately connected with the arts to be suspended without being felt; the wants of the Republic soon restored them to their former sphere, and the respect and gratitude of the nation raised them to power. It was in fact principally by the exertions of this class of men, that her armies were furnished with the means of pursuing their victorious career; and France was indebted to the chemists for the knowledge of resources within her own bosom, which, until that period, had been derived from foreign aid, and external commerce. Secure in the respect of the people, and the protection of the government, their labours were pursued without fear, and their results published without danger. The scientific mind of Berthollet enriched every department which it investigated, the analytical researches of Vauquelin were unrivalled, and the eloquence of Fourcroy diffused a charm over even the most abstruse points of the science. Under the imperial dynasty, the chemists were not only protected, but caressed, titles of nobility were conferred upon the distinguished philosophers of France, and though the motive which produced the patronage of Napoleon may be questionable, the world must have viewed with pleasure the honourable alliance of mind with rank, and knowledge with power.

The advantages which have been derived from the system of Lavoisier have been great, but the progress of the science has brought to light a multitude of facts irreconcilable with its doctrines, and incompatible with its laws; and whether restricted to the subject of combustion, or extended to the whole arrangement, it must now appear partial in its application, and inadequate to the explanation of its phenomena.

There are many substances which, during their mutual action, produce heat and light, and even the appearance of flame, which are not known to contain oxygen. Combustion, then, does not always require the presence of oxygen, and this principle is not essential to the process. There is no doubt that the combustible processes, with which we are most familiar, depend upon oxygen gas, and the error of Lavoisier consisted in applying the principles, deduced from common facts, to those the observation of which is more immediately connected with the pursuit of chemistry.

The light produced in combustion was supposed by Lavoisier to be derived from the oxygen gas, but later researches have shown with more probability that it proceeds from the inflammable body. The heat evolved in this process was inferred to proceed from the gas, with the basis of which it was combined, during its condensation or change of form; or in consequence of a diminution of capacity. But the idea of *combined* caloric is hypothetical, and with respect to change of capacity, it has been shown by M. M. Berard and De la Roche, that this principle of Irvine and Crawford is totally inadequate to explain the high temperature produced in most cases of combustion; in many of these, there is no condensation, and no latent heat can therefore be extricated; in others either the diminution of capacity is too small, or there is actually an increase, so that the result should be rather the absorption than the extrication of caloric. When the metal called potassium is gently heated in a peculiar gas, called *sulphuretted hydrogen*, and which is destitute of oxygen, it burns with flame, the sulphur previously united with the hydrogen is found after the process to be combined with the potassium, and the volume of the remaining gas is unaltered. The doctrines neither of Lavoisier, nor of Crawford, can explain the cause of the combustion, and the production of light and heat; and as many analogous facts have been observed, and will be stated in the chapter on Combustion, the conclusion must be drawn that these doctrines admit of only a par-

tial application. The phenomena both of light and heat appear to depend less upon the presence of any one element during chemical action, than upon the rapidity and intensity of mutual combination, and hence a regular gradation may be observed in the amount evolved of heat and light, from the combustion which is so brilliant as to pain the eye, to that in which the production of light is scarcely perceptible, in cases too in which oxygen is not concerned.

Neither is oxygen exclusively the principle of acidity, for this quality exists in bodies, the composition of which has been accurately determined, and in which that substance is not known to exist. All the *hydracids* are compounds of bases with hydrogen, and in these cases hydrogen must be considered as the acidifying principle. In fact, the idea of a universal principle of acidity is altogether incorrect, for though oxygen enters into the composition of some acids, and hydrogen into that of others, they both form with other elements the class of alkalis, which, in all their properties are opposed to the acids. Thus, potash, and soda, and lithia, are metallic bases combined with oxygen; and ammonia results from the union of azote and hydrogen. Inflammable bases by their combination with oxygen form acids, oxides, or alkalis, according to their nature, and the circumstances of the experiments; hence the same oxygen, which in one case produced an acid, may, by merely changing its base, compose an alkali. When sulphur is consumed in oxygen gas, it forms with it an acid which is permanently elastic; but if potassium be heated in this acid gas, it takes the oxygen from the sulphur, and is itself converted into potash, or a strong alkali. If there be such a thing in chemistry as an acidifying principle, there is reason for believing that it must arise from the joint action of oxygen and hydrogen.

The general doctrines, therefore, as well as the theory of combustion of Lavoisier, must now be considered as incorrect and partial in their application. But no other system has yet taken its place. The facts and anomalies opposed to

them are comparatively of recent observation ; the subject of combustion is still under investigation, and the analogies, and indeed the nature of some of the bodies, which by many are ranked among the elements, are not yet universally established. The nomenclature and the arrangement of the subjects of chemistry, proposed by and adopted from the French, are still followed by chemists, so far as is practicable, and until the sources of heat and light, the nature of combustion and flame, and the cause or power which occasions chemical phænomena, are unfolded, that system must still be followed.

The department of chemistry which has of late been most successfully investigated, and which has terminated in the establishment of a general truth, is that which relates to the quantities of combining bodies, or to the doctrine of multiple proportions.

The theory of the operation of the power which produces chemical phænomena, has, like most of the philosophical doctrines of the science, undergone successive modifications. When Newton applied to the particles of bodies the principle which he deduced from the motions of masses of matter, and considered affinity as attraction, it was to be inferred, that if carried to its full extent, the effects must be modified by the number of the particles, and the distances at which they were placed. But the French chemist, Geoffroy the elder, having remarked that bodies might be successively separated from others with which they had been previously combined, inferred that the power of attraction not only varied in intensity in different substances, but likewise that the order of the relative attractions was uniform and constant. Hence, if this order could be once established by experiment, it would be easy to reduce them to method, and by constructing tables in which the affinities of one substance for a number of others might be expressed, the arrangement would greatly facilitate the acquisition of useful knowledge, and improve the art of chemical analysis. This idea was carried into execution, and in the year 1718 he published the first tables of affinity,

founded upon experiment, and arranged with the utmost simplicity. These tables were enlarged by succeeding chemists, but it is principally to the illustrious Bergman that we are indebted for the first philosophical treatise upon affinity, and for a suite of tables which was extended to the relative attractions of all chemical substances then known. This important Treatise was first published in 1775, and afterwards in his *Opuscula Chemica*, in 1783.

Bergman believed that affinity was constant and invariable in its force, that it differed in different bodies, and that this difference in power might be expressed by numbers. Hence, he applied to this principle the terms *Elective Attraction*, by which he meant to express the fact, that when a third body was presented to a compound of two substances, for one of which it had a greater affinity, than that by which they were united, it would decompose such a compound, and combine with the whole of one of the substances, and disengage the other. Thus A and B, in consequence of their mutual affinity, will combine when presented to each other in certain circumstances, and form a compound; but if C have a stronger attraction for A, than A has for B, the compound, when C is brought into contact, will be decomposed, the whole of A will unite with C, and B will be separated. Proceeding upon this principle, he undertook to verify the observations of preceding chemists, to examine more extensively the elective affinities of different bodies, and to present a complete series in the forces of attraction, these forces being estimated by the order observed in decompositions, which were effected in two ways, by heat and by solution, or the *dry* and the *humid*. Some idea may be formed of the immense labour required in these investigations when it is known, that his tables occupy 59 columns, and that reiterated experiments were probably necessary to determine this order with precision.

The profound works of M. Berthollet on Affinity, and on Chemical Statics, which were published about the commencement of the present century, gave a very different view of

this subject. This philosopher considered affinity as attraction, and differing from gravitation probably only in the subjects upon which it operated; and that in this respect there was no real distinction between chemistry and mechanical philosophy. Hence, upon the principles of Newton, the quantity of matter must have an influence upon combination, and it is therefore laid down as an axiom, that affinity is in the ratio of the attraction and acting mass. It follows, that quantity of matter may compensate for feebleness of affinity, that a substance may decompose a compound, though its affinity for either of the constituents may be weaker than that by which they are united, and that an acid, for example, will be shared between two bases in proportions dependent upon their affinities and acting masses. The tendency of bodies is to combine, and if decomposition take place, it must be the result of cohesion, elasticity, insolubility, &c. Affinity, therefore, is not elective; nor are substances to be considered as disposed to unite in determinate proportions, but when such combinations are formed, they result from the circumstances in which the bodies are placed.

One of the most important general facts respecting combination was discovered by Richter, and the researches which led to it occupied his attention from 1791 to 1800. The law which he deduced was this, "if two neutral solutions be mixed together, and a decomposition follow, the products which result will be, nearly without exception, also in a neutral state. But if the two solutions, or one of the two were not neutral, neither will the products be neutral." The consequences of this discovery were obvious. It enabled the chemist to find the proportions necessary to the neutralization of acids and bases, to determine the ratios in which different bodies combine, and to designate these ratios by numbers. Hence it has been practically applied by Dr. Wollaston, and in his *Scale of Chemical Equivalents* which is constructed upon logometric principles, he has given to the chemist an in-

strument admirably calculated to facilitate his progress in all analytical investigations.

The researches, the observations, and the analyses, which were made on the subject of combination, all tended to one point, and at length the important conclusions were drawn that when bodies combine chemically and intimately with each other, they combine in determinate quantities; and that when one body unites with another in more than one proportion, it exceeds by a ratio which may be expressed by some simple multiple of the first proportion. This simple law of Dr. Wollaston expresses the results of his own labours, and of those of Dr. Higgins, Mr. Dalton, M. Gay-Lussac, Dr. Thomson, and professor Berzelius. It is the essence of the doctrine of *Definite proportions*. This general fact is one of the most interesting and important discoveries which have been made by modern chemists. It extends the principle of Richter to all cases of chemical combination, and by allowing the proportion of any elementary body to be considered as a standard, it enables the chemists to find the ratio in weight of the proportions of other bodies with which it is capable of uniting, and if the first be designated by unity, all the others may be expressed by numbers which bear certain ratios to unity.

The subject of definite proportions is founded upon fact, but in attempting to account for the combination of bodies only in certain ratios, chemists have necessarily been drawn into hypothesis, and the *Atomic theory*, which appears to have been suggested by Dr. Higgins, but modelled and arranged by Mr. Dalton, offers assumptions which cannot be substantiated, and reasons upon data which cannot be proved. The position that where there is but one known compound of two elements, it is composed of one atom of the one, united with one of the other, is gratuitous. It may consist so far as we know of two or more atoms of the former, combined with two or more atoms of the latter. It is equally a gratuitous assumption, that in several combinations of the same elements,

one of them always enters into their composition as unity or one atom. The foundation of the theory itself is hypothetical; for we know nothing of the real constitution, or essence of matter, the existence of atoms can never probably be demonstrated, and the attempts which have been made to estimate their relative weights are founded upon data which are purely speculative. These circumstances, independently of the difficulties which it offers when practically applied, are perhaps sufficient to create a doubt whether the atomic theory will ever be considered as one of the fundamental doctrines of chemistry. Yet the science is greatly indebted to the philosophers who maintained it, for most of the facts upon which the laws of definite or multiple proportions are founded.

The beautiful generalization of M. Gay-Lussac, that the elastic fluids always combine in volumes which bear simple ratios to each other, has contributed in a remarkable degree to establish those laws, and to facilitate investigations into the composition of gaseous bodies. In fact, there is no department of the science which has not been improved by the labours of this accomplished chemist. Associated in many of his researches with M. Thenard, their united efforts brought to light many curious and important facts respecting voltaic electricity; they discovered a method of decomposing potash which yielded a comparatively large product of its singular base; they first obtained in considerable quantities and demonstrated the properties of boron; their researches into the nature of chlorine suggested the idea that it might be regarded as a simple body; and they first procured *fluoric acid* in a state of purity. The elaborate memoir of M. Gay-Lussac on Iodine, while it establishes the nature and properties of that curious and interesting body, contains the results of profound inquiries into the subject of philosophical chemistry. The composition of *prussic acid* which had been the subject of so much experiment, and the cause of so much speculation among chemists, has been determined by

the admirable researches of M. Gay-Lussac, and he has added another member to the class of elastic fluids. These are but a few of the discoveries with which this distinguished man has enriched the science of chemistry. Much is still to be expected from him and Sir H. Davy; they are rivals in fame, and science will gain either by their union or division in opinion.

Another subject which has been prosecuted with ardour, and which has terminated in the discovery of the laws which regulate the structure of bodies, is crystallography. The fact that the immense variety of crystals which are disseminated throughout nature, may be reduced, by mechanical division, to a few elementary forms, has been demonstrated by M. Haüy; and the researches of this philosopher have unfolded to us one of the most beautiful and recondite of the processes of nature. The subject is again presented to us in a novel and interesting point of view by the labours of Dr. Wollaston and Mr. Daniell, and the theory which considers the elementary parts of bodies as spheres may be considered as completed, for the principle assumed is sufficient to account for the structure of all crystallized bodies, though we may be still ignorant of the essence or constitution of matter. The profound researches of Dr. Brewster, and of M. M. Biot and Arago into the subject of the *Polarisation of Light*, promise to develope still more perfectly the structure of crystals, and the laws by which the connexion between mechanical philosophy and chemistry may be more completely established.

As an art, chemistry has made a more rapid and certain progress than when viewed as a science. The analyses of the present day are not only more refined, but also more perfect than those of former periods. The Essays of Klaproth, the scattered memoirs of M. Vauquelin, the Bakerian lectures of Sir H. Davy, and the *Recherches Physico-Chimiques* of M. M. Gay-Lussac and Thenard, exhibit, in a remarkable degree, the precise and extensive knowledge which has been acquired of chemical affinity, and the power of the

chemist in separating the elements of compounded matter. The art of analysis may perhaps be improved by the development of the general fact, that the tendency of bodies is to combine in definite and multiple proportions, but all attempts to determine the composition of such bodies by the application of the laws or canons of this theory, must have an injurious effect, by inverting the natural order of physical investigation, and causing us to reason rather from principles than facts. Our notions of the composition of bodies must be derived from the results of actual analyses, and the conclusion founded upon them will be general so long as new facts coincide with them: but when it is said that *ammonia* must contain a certain quantity of oxygen, because, like the fixed alkalies, it is capable of combining with, and of neutralizing the properties of a given weight of acid, we step beyond knowledge, and by the application of a principle, which in other cases may obtain, deviate into hypothesis. The chemist has never detected the presence of oxygen in azote, nor ammonia; hence, it is a mere assumption to say that it exists, and no reasoning from analogy can be considered as decisive in chemistry.

In reviewing the history of this science, the circumstance which first attracts attention is the series of revolutions which its theories have undergone. In reasoning upon the future, from the experience of the past, it must appear at least doubtful whether its limits will ever be accurately defined; whether the time will ever arrive, when the mutual relations and dependence of its parts shall be precisely determined, its theories be rendered permanent, and chemistry shall assume the form of an exact and complete science. At the present time it must be acknowledged to be unsettled, and though the generalizations of Lavoisier are daily becoming more partial and restricted in their application, no novel and permanent system has as yet been substituted. The nature of the power which produces chemical phenomena is not yet developed; the causes of heat and light still remain to be de-

monstrated; the theory of the constitution of Chlorine and Iodine cannot be considered as universally established; nor are chemists yet decided upon the composition of the bodies which exhibit acid, or saline properties. The effects, which it is the province of the chemist to explain, arise from the two forces of attraction and repulsion; the doctrine of polarities may perhaps at some future period be considered necessary to the explanation of their action, and polar arrangements be found connected with their operation. At what period chemistry may cease to be a progressive science cannot be foreseen, but at the present moment it is fortunate in possessing philosophers who cultivate it with zeal, and are rewarded with success. Much has been given, and it is hoped much still remains to be given to society by Sir H. Davy, Dr. Wollaston, Mr. Dalton, Mr. Brande, Dr. Thomson, and Dr. Murray, in Great Britain; by M. M. Vauquelin, Gay-Lussac, Thenard, Dulong, Berard, and De la Roche, in France; by M. M. Stromeyer, Dobereiner, and John, in Germany; and by Professor Berzelius and his pupils in Sweden.

The preceding pages must be considered as a very general and imperfect outline of the history of chemistry; but it will be sufficient to show, that great minds have been employed in the study of nature, and that when properly directed, they have developed facts, and unfolded discoveries, which exerted a direct and important influence upon the relations of life. The connexion between this science and the arts, and the improvements in the one, from the application of principles derived from the other, are seen and acknowledged. Chemistry now constitutes an essential part of a liberal and enlightened education, and while the senses are gratified by the demonstration of its phænomena, these phænomena become the medium through which the mind perceives a general physical truth.

But the pleasure which is experienced in pursuing this interesting science, and even the benefits that result to society from the practical application of its laws, ought to be consid-

ered as subordinate to the influence which the cultivation of a knowledge of nature should exert upon the moral character. "The investigation of nature," says Dr. Crawford, "is peculiarly calculated to instruct us in that most important of all arts, the art of living. To whatever height we may ascend in tracing the causes, which regulate the system of the world, our views must at last terminate in an uncaused Being, in whom all the beauty and order, all the wisdom and power, displayed throughout the universe, is centered. Every step which we advance in the cultivation of natural knowledge, contributes more firmly to establish this great truth; because it affords an additional proof of exquisite skill and contrivance in the formation of the world. By thus showing us the Deity in his works, the contemplation of nature leads to consequences, in the highest degree interesting to intellectual and moral agents. When we look around us, we perceive that every part of the material world is governed by general laws; and when we reflect, that in this vast system of things, a race of beings exists, to whom the Deity has communicated a portion of his intelligence and activity, we cannot avoid concluding, that laws must have been ordained for the government of such beings, as well as for that of all other parts of the universe. Moreover, in contemplating the plan of the universe, we perceive that the whole is arranged into one great system; that an uninterrupted chain of connexion extends throughout the various classes of beings; that nothing in nature is quiescent; that the past has been subservient to the present, as the present will be to the future; in a word, that all things are in a state of progression, and apparently tend toward the accomplishment of a great design, which seems to have influenced the whole series of events since the creation, and which probably will not be completed, till the present scene of things is closed by the dissolution of the world.

"If we compare the various classes of beings which fall within the reach of our observation, we perceive that intelli-

gent and moral agents hold the highest rank ; and, consequently, of all the laws which regulate the system of nature, those that have been established for the purpose of maintaining harmony and order in the intellectual world, must be the most important.

“ It is thus that a just estimate of the value of the several objects, which present themselves to our view, in a general survey of the universe, informs us, that obedience to the moral law constitutes the supreme perfection of the most exalted orders of created beings ; and as consummate moral excellence is the highest point of eminence, which the imagination can conceive an intellectual nature to attain, we are led to consider this as the first attribute of Deity.

“ Hence, in investigating the final causes of the system of the world, there are none which appear more important, or more worthy of an infinitely perfect mind, than that the universe should be considered as formed for the purposes of communicating happiness to sensitive beings, and of training moral agents in the rudiments of wisdom and virtue.—In fine, we have reason to believe that the advancement of moral excellence is the ultimate point, towards which the movements of this vast system are directed ; and as it seems to have been the great final cause which gave rise to the creation of the material world, so it is probable, that it will be the principal aim of the Deity in its dissolution.”

ELEMENTS
OF
CHEMISTRY.

=

PART I.

*Of the forms and general properties of Matter ; and of the Agents
or powers, which are concerned in the production of
Chemical Phenomena.*

I. **T**HE essential properties of matter are extension and impenetrability. Of its essence or real nature we are ignorant, and it is impossible at present to decide, whether material bodies are mere collections of properties, which produce peculiar impressions upon our organs, or whether they have a sub-stratum or an actual existence. The hypothesis has been supported, that what we call matter consists in spheres of attraction and repulsion. It is however the general belief, that ponderable bodies are formed of minute particles or atoms, which are solid, impenetrable, indestructible and indivisible. The forms, of which aggregates of these particles are susceptible, may be reduced to three classes, solids, liquids and airs.

II. In solids the atoms appear to be united with the greatest force ; in many cases they are separated with difficulty, and, when once removed from each other, they cannot be easily made to reunite by mechanical means. The properties of solids depend upon the nature of their minute parts, the mode in which they are applied to each other, and the force by which they are retained in apparent contact, and, as these conditions are varied, the individuals of this class differ among them-

selves in degrees of hardness, density, lustre, elasticity, &c. In consequence of a peculiar arrangement of their particles, many of this class of bodies exhibit regular geometrical forms.

III. Liquids are bodies, the particles of which, without losing the power of remaining in contact, are capable of moving freely over the surfaces of each other. In small masses they assume a spheroidal figure. They are incompressible, or at least yield to equable pressure only in a slight degree; and they differ from one another in colour, density, tenacity, and transparency.

IV. Airs or gases, are highly attenuated, elastic and compressible fluids, the particles of which are endowed with a repulsive energy, and are removed from each other to much greater distances, than those of liquids or of solids. They are for the most part destitute of colour; they are transparent, and therefore invisible; and they differ exceedingly in their physical and chemical properties.

The forms of matter and the changes, which these forms experience upon our globe, are the results of motions, which may be referred to the operation of Attraction, Caloric, Light, or Electricity.

V. The phænomena exhibited in the œconomy of nature sufficiently prove, that there is a power continually in action, the tendency of which is to bring bodies into contact. This force, the influence of which extends throughout the universe, is attraction, or gravitation. Its cause is unknown, and the term itself is to be considered as an expression for an ultimate fact. This power operates upon masses at sensible distances with a force, proportional to the quantity of matter, and inversely as the squares of the distances. Attractive powers are also exhibited by the particles of bodies at inappreciable distances, but it is at least doubtful whether the motions, thus occasioned, arise from the exertion of the same force which produces the phænomena of gravitation.

Attraction is modified or controuled by an antagonist power, to which has been applied the name of Repulsion; but

whether it be distinct from, or identical with one of those, which are mentioned below, has not been decided.

VI. The cause, which produces in us the sensation of *heat*, must be viewed as an active and general power of nature. Its influence is widely diffused, and the different degrees of force with which it acts, give rise to the most important and extensive effects. It is recognized by the name of *Caloric*, and its mode of action is repellent.

VII. Light seems to operate upon the different systems of our globe, with much energy and effect; but its force, as a chemical agent, has not been so minutely investigated as that of caloric, nor have the limits of its power been so accurately defined.

VIII. Of the distance to which electrical influence extends, we are ignorant. That electricity operates upon masses of matter at sensible distances, is well known; and that it is capable of communicating attractive and repellent powers to the particles of bodies, seems to be established.

The investigation of the effects, which the motions produced by these powers occasion, embraces the most important and interesting phænomena of Chemistry. They will be succinctly stated in the following chapters.

CHAPTER I.

Of Attraction.

IX. Attraction has been divided into two kinds. When it acts upon aggregates of particles at great distances, it is called Remote attraction, or more simply Gravitation; but when it is employed in bringing into contact the minute parts of bodies, it is termed Contiguous attraction. In some cases, the latter power is employed in uniting particles of the same nature, while in others it combines atoms of different natures; in the first, forming bodies, the properties of which are the same as those of each of the particles; in the second, producing compounds, in which the component parts can be no lon-

ger identified. Hence this force has been subdivided into the attraction of Cohesion, or of aggregation; and Chemical attraction, or affinity.

SECTION I.

Cohesion.

X. Cohesive attraction is the power, by which particles of the same nature are brought into contact and retained in that situation. A mass of iron or of lead is to be considered as an aggregate of an undefined number of particles, each of which, so far as we know, has the same title to the name of iron or lead, as the body resulting from their approximation. This force exists between the particles of all solids, and to a less degree among those of all liquids; the energy of the attraction varying with the nature of the minute parts. Hence we find that great mechanical force is necessary to separate the particles of some solids; in some, the distances between them may be increased to a certain degree without removing them from the spheres of their mutual attraction, while in others the power applied suddenly destroys the union. From these circumstances result the properties of solids, such as their hardness, brittleness, elasticity, malleability, ductility, tenacity and the high polish, of which many of them are susceptible.

The force of cohesion in solid bodies is measured by the weight necessary to separate their particles. A rod of a certain diameter is suspended perpendicularly, and weights are applied to the lower extremity until it is broken. The following tables exhibit the results of some of the experiments made by Muschenbroeck upon metals, &c. The numbers express the pounds avoirdupois, which are just sufficient to tear asunder a rod of each of the bodies, whose base is an inch square.*

I. *Metals.*

Steel, bar	-	-	135,000	Copper, cast	-	28,000
Iron, bar	-	-	74,500	Silver, cast	-	41,500
Iron, cast	-	-	50,100	Gold, cast	-	22,000

* Thomson's System of Chemistry, vol. iii. p. 113, 5th edition.

Tin, cast	-	-	4,440	Antimony	-	-	1,000
Bismuth	-	-	2,900	Lead	-	-	860
Zinc	-	-	2,600				

II. *Woods.*

Locust	-	-	20,100	Ash	-	-	12,000
Beech, oak	-	-	17,300	Plum	-	-	11,800
Orange	-	-	15,500	Fir	-	-	8,330
Elm	-	-	13,200	Walnut	-	-	8,130
Mulberry	-	-	12,500	Poplar	-	-	5,500
Willow	-	-	12,500	Cedar	-	-	4,380

III. *Bones.*

Ivory	-	-	16,270	Whalebone	-	-	7,500
Bone	-	-	15,250	Tooth of sea calf			4,075
Horn	-	-	8,750				

XI. The particles of liquids are much less coherent ; they are easily displaced and removed from each other ; but even in these this force still exists, as is proved by the spherical form of their drops. The upper surfaces of liquids enclosed in tubes are convex, and the degree of convexity is proportional to their density ; whence it happens that this property is most conspicuous in mercury. When two globules of mercury are brought into apparent contact, they mutually incorporate and form one mass. Drops of liquids may be suspended from the surfaces of solids, and water, it is well known, will ascend in capillary tubes, and in porous bodies, contrary to its gravity. Whence it appears that this force operates upon masses of different natures, provided that they may be again separated by mechanical means, and that their contact be not followed by change of properties.

XII. When this attractive force operates at, or is supposed to be confined to the surfaces of masses, it has been called Adhesion. Thus, various crystallized bodies are found imbedded in an uncrystallized base of a different nature and adhere to it with much pertinacity. Two polished bodies applied to each other require a considerable force for their sepa-

ration ; and smooth surfaces, when brought into contact with a liquid, adhere to it with a power, which varies according to the nature of the solid. The following table, from the experiments of Mr. Ruhland, exhibits the weights which were found necessary to separate equal surfaces of different bodies from the same liquid.

Water twice distilled.

Zinc	-	-	77 grs.	Tallow	-	-	76 grs.
Wax	-	-	79	Lead	-	-	74
Sealing wax	-	-	70.5	Marble	-	-	77
Glass	-	-	75.5	Sulphur	-	-	80

Oil of Almonds.

Marble	-	50 grs.	Wax	-	56 grs.	Tallow	-	54 grs.
--------	---	---------	-----	---	---------	--------	---	---------

20 grs. of concentrated nitric acid in 2 oz. of water.

Glass	-	-	64 grs.	Wax	-	-	70 grs.
Lead	-	-	67	Tallow	-	-	69
Sulphur	-	-	65				

Concentrated solution of Potash.

Zinc	-	-	65 grs.	Tallow	-	-	66 grs.
Sulphur	-	-	67	Glass	-	-	64
Wax	-	-	69				

Other experiments with diluted sulphuric acid, saline solutions &c. exhibited the same difference in the forces with which adhesion took place.* It is hardly probable that this attractive power should be confined to the surfaces of bodies ; the effect may perhaps be more justly referred to the entire masses. By Dr. Thomson, adhesion is considered as exhibiting the characteristic marks of chemical affinity, and as affording a particular case of the action of that power.

XIII. The power of cohesive attraction may be lessened or destroyed by the operation of heat, by mechanical violence, and by the influence of a more powerful attraction.

* Annals of Philosophy, vol. vii. p. 20.

1. When a fusible body is exposed to the influence of heat, the volume is at first augmented, and this increase of bulk is the consequence of the separation to a certain degree of its particles. Cohesion is lessened, although not destroyed, and if heated zinc, for example, be struck with a hammer, much less force will be required to disintegrate it, than if it were at the ordinary temperature of the air. If the heat be continued, the particles of the metal will be so far removed from each other, as to allow of free motion, and it will become liquid. By raising the heat still higher, while the metal is not in contact with the air, all cohesion will be removed and it will be resolved into vapour or an elastic fluid.

2. The particles of bodies, which are united by cohesive attraction, may be in a great measure separated from each other by mechanical action, and the operations of grinding, rasping, pounding and levigating, are so many methods of removing them from their spheres of attraction, and of obviating a state, which presents an obstacle to their mixture, or combination with other matter.

3. If a mass of lime be immersed in vinegar, its bulk will gradually lessen, and, after a certain time, it will disappear. In this experiment, then, another attractive force has been introduced, the power of which is obviously superior to the attraction of the particles of lime for each other, and consequently they are separated. This power is chemical affinity. It sometimes happens however, that cohesive attraction is superior to this power, and that mechanical division must be employed before the latter can become effective ; examples of which may be found in the tin stone, ruby, sapphire and adamantine spar.

XIV. The nature of cohesion, says Dr. Thomson, has been more happily explained by Boscovitch, than by any other philosopher. According to him, the particles of bodies cohere together, when they are placed in the limit of attraction and repulsion. Two particles, when situated at a certain distance, mutually repel each other ; this repulsion gradually

diminishes as the distance between them increases, till at last, when the distance reaches a certain magnitude, the repulsion ceases altogether. If the distance be increased ever so little, the particles now, instead of repelling, attract each other, and this attraction increases with the distance, till at last it reaches its maximum. From this point it gradually diminishes, until the particles are at a certain distance, when it ceases. If the distance be again increased, mutual repulsion takes place. Hence the insensible distance between two particles is supposed by Boscovitch to be divided into an indefinite number of portions of alternate attractions and repulsions; and cohesion, strictly speaking, is not a force, but the interval between two forces.*

XV. During the exertion of cohesive attraction, the particles which are the subjects of it either unite with each other, in a confused manner, so as to constitute bodies, destitute of regularity of form, or any physical relation of parts; or they are brought together in a determinate mode by which regular solids, susceptible of geometrical admeasurement, are produced. This last process is called *Crystallization*, and the product is a crystal.†

Crystallization.

XVI. In order to produce bodies with crystalline forms, it appears that freedom of motion among their particles is absolutely necessary. This mobility may be effected in two ways, 1. by increasing their temperature to a certain degree, and 2. by dissolving them in some liquid.

XVII. The expansive power of heat is such, that when bodies are exposed to its influence, their particles proportionably recede from each other, and their volumes are augmented. This increase of bulk proceeds to a certain extent, beyond which the particles acquire mobility and the solids are con-

* System of Chemistry, vol. iii. p. 114. 5th ed.

† From *κρυσταλλος*, the Greek word for Ice.

verted into liquids. If, in this state, they be rapidly cooled, the masses will again become solid, but, instead of discovering regular geometrical forms, their texture will, at most, be merely crystalline. But if the temperature be slowly reduced, the particles will arrange themselves in a determinate manner, and the result will be the formation of perfect crystals. Thus, when sulphur is melted in a crucible and is allowed to cool until a crust form upon its surface, if this crust be pierced and the liquid beneath be allowed to flow off, the whole surface of the cavity will be found covered with delicate prismatic crystals. When managed in the same way, several of the metals may be made to exhibit the same phænomenon.

All bodies which are liquid at common temperatures, but which are capable of becoming solid by exposure to cold, passing immediately from one form to the other, without any gradual hardening like oil, or tallow, assume a crystalline state, and congelation, in these instances, is the act of crystallization. Water affords a familiar example, and the forms and appearances of the ice are dependent upon the quantity of liquid, and the rapidity or slowness with which the heat has been withdrawn. Hence arises the difference between frost, and common ice.

XVIII. Vapours, during their condensation, frequently assume the crystallized state. If the powder of corrosive sublimate be put into a dry flask, the mouth of which is slightly obstructed and be exposed to the heat of a lamp, or a sand bath, it will rise in vapour, and, when it comes in contact with the upper part of the vessel, its heat will be diminished, it will be condensed and assume the form of long and slender prismatic crystals. The vapour of metallic arsenic condenses in brilliant tetraedal crystals of a bluish white colour; and many of the salts exhibit the same phænomenon. Flakes of snow often present the most perfect and beautiful crystals, and their forms are very numerous, the varieties probably depending upon the temperature and motion of the air through which

they descend. They are most perfect when the atmosphere is calm and the temperature is not many degrees below the freezing point of water.

XIX. The finest crystals are obtained from solutions, and by two methods ; either by dissolving as large a quantity as possible of the solid in the liquid, and then allowing it to cool gradually ; or by forming a solution at common temperatures, and afterwards withdrawing the liquid by slow evaporation.

The solution of salts in water, for example, is found to be governed for the most part, by the degrees of heat. Most of them are dissolved in larger quantity by hot than by cold water, and, consequently, when the temperature of a solution thus made, is reduced, a proportional part of the salt is deposited ; and as this deposition is a gradual process, the minute parts are attracted toward each other in such a way as to form regular solids. This is the case with Glauber's salts, nitre, green vitriol, and a multitude of saline bodies.

The same ultimate effect is produced by diminishing the proportion of aqueous fluid by evaporation, either by exposing the solution to the air, or to a moderate heat. The most perfect forms are obtained by vapourising a portion of the water, allowing the vessel to remain at rest, and very gradually reducing its temperature. The product in such cases is generally small, but the whole of the solid may be procured in regular crystals, by repetitions of the same process.

XX. In a few cases, the solvent power of water appears to be diminished by increasing its heat, or the saline substance is partly decomposed. Thus, if the liquid, which is formed by allowing the metal, called bismuth, to remain for some time in contact with diluted aqua fortis, be gently heated, small and delicate crystals of a silvery white, will be formed and separated, before any portion of the water is evaporated. It is stated by M. Gay Lussac, that when the solution of the salt, called acetate of alumina, is exposed to heat, a portion of its base will be deposited, and that this portion will be redissolved, as the temperature is reduced.

XXI. It has been found that the formation of crystals is facilitated by immersing in the solution, in which this process is going on, some foreign body which shall answer as a nucleus or attracting point, around which the particles, as they are deposited, may be attached. Many of the salts of commerce will be found concreted around sticks or twigs; and the fine crystals of sugar, which are sold as an article of luxury, most usually exhibit a thread passing through the centre of the mass. A crystal of the same nature put into a saturated solution of a salt, answers a similar purpose; and by frequent turning, so that the different sides shall be successively exposed to the liquid, very large, perfect and beautiful forms may be obtained; a fact, which was first noticed by Le Blanc of Paris.

In certain states, crystallization may be produced by agitation. Water and other liquids, when in small masses and perfectly at rest, may be cooled several degrees below their usual crystallizing points and still preserve their fluidity; but if they be agitated, and particularly if the motion be of that kind which shall alter the relative situation of the particles, fine feathery crystals will be seen to shoot through the liquid mass, and in a few seconds the whole will be converted into a soft solid. Solutions of some of the common salts, made at a high temperature, may, when their heat has been gradually withdrawn, be made to crystallize in the same way. The process may also be effected immediately by dropping into the solution a crystal of salt of the same nature as that which is already dissolved.

It has been said by Dr. Higgins, that pressure of the air, or any pressure equivalent to it, has a considerable influence in producing crystallization; and that when this pressure upon a saturated solution, made at a high temperature, is intercepted, it does not crystallize, as its heat is reduced; but that so soon as the air is readmitted, the process commences. Later experiments do not confirm this opinion. M. Gay Lussac has shown that the pressure of the air has no influence

upon the solvent power of water ; and this conclusion appears to be verified by the results of an extensive suite of experiments made by Dr. Coxe.*

Besides, in these cases, the air being excluded, the vapour of the water which fills the upper part of the vessel, must act the part of the atmosphere, and render the difference between the two states much less than has been imagined. When the air is admitted into a vessel containing a super-saturated solution of a salt, it acts probably only by its sudden impulse upon the surface and analogous therefore to motion by other means.

XXII. Water appears to constitute an essential part of crystals. It exists in them in a solid state, and is called water of crystallization. The proportion varies in different salts ; the soda of commerce contains more than half its weight ; alum and epsom salt nearly the same quantity ; while nitre affords but eighteen, common salt about six, and sulphate of potash eight per cent. of water. This water appears to exist in them in the form of ice ; the force also, by which it is attracted, is equally various. It is retained in some by a feeble attraction and passes off merely on exposure to the air. In such cases the texture of the crystal is gradually destroyed and it falls into a powder. This process is called *efflorescence*, and it is well exemplified in Glauber's salts. In other instances the force, which unites it to the other constituents of the salt, is more powerful and it is disengaged only by exposure to heat, or by separating the constituent parts of the saline compound. In many cases, although the salts contain water, yet they still have an attraction for an additional quantity, and on exposure to the air, take it from the atmosphere, and at the same time, become liquid. Such salts are said to be *deliquescent*. The quantity thus absorbed seems to operate only in rendering the salt liquid, and no part of it is solidified. The salts which deliquesce, or in other words have a strong attraction for water, are often usefully employed by

* Annals of Philosophy, vol. vi. p. 101.

the chemist to deprive the different airs of their aqueous vapour, when they are required in a dry state for refined and delicate experiments.

The salts which contain much water of crystallization become liquid on exposure to heat, because, at a high temperature, the solvent power of water is so much increased, that it is able to dissolve the solid compound. Of this fact, alum is a familiar example. The process is termed aqueous fusion. Some salts have so strong an attraction for water, that they are obtained in a solid, crystallized state, with great difficulty, such for example as muriate of copper; there are others, e. g. red sulphate and muriate of iron, which cannot be procured in a crystallized form. In some such cases the addition of strong spirit of wine, which has a tendency to unite with water, may withdraw so much of that liquid, as to allow the salt to assume the solid state.

XXIII. Water which has dissolved one salt to the point of saturation, will still take up a considerable proportion of a second and even of a third. Sea water contains several well known saline compounds. In such cases, as the salts have different degrees of solubility, they may often be obtained separately by a gradual evaporation of the water, the least soluble being the first to separate. The water of the ocean, evaporated to a certain degree, yields common salt; evaporated still further, it deposits Glauber's salts, and the remaining liquid holds dissolved a compound containing magnesia. Mr. Kirwan has stated the singular fact, that if into a saturated solution of two salts in water, a crystal of either be immersed, the salt of the same nature will be first deposited. It appears therefore from this fact and others already mentioned, that cohesive attraction is exerted between a solid salt and particles of the same nature in a state of solution, and hence it is easy to perceive the advantage which arises from the employing of a nucleus in processes of crystallization. It sometimes happens, however, that the mutual attraction of two salts for each other is such, as to cause them to crystallize

from a common solvent at the same time, and the compound will sometimes take on a form which belongs to neither, in a separate state; at others, the crystalline form will be the same as that which is characteristic of one of the salts. Such salts are called by M. Berthollet *surcompounded*.*

XXIV. Crystallization, if it be rapid, as in super-saturated solutions, produces at the moment an increase of temperature in the whole mass. This fact may be proved by previously suspending the bulb of a thermometer in the solution, when recently prepared, and, after it has cooled to the temperature of the surrounding air, producing crystallization by the methods above mentioned. As the crystals form, the mercury will rise in the instrument. The increase of heat will even be perceptible to the hand. If a thermometer be plunged into water which has been cooled without freezing, to 25° , the liquid will suddenly congeal and the temperature will rise to 32° .

Bodies, generally speaking, increase in bulk during crystallization. Ice, it is well known, occupies a larger space than the water, from which it is formed. Hence its specific gravity is less than that of an equal bulk of that liquid. The same is the case with iron. But mercury, although in congealing it assumes a crystalline texture, is diminished about $\frac{1}{3}$ of its volume.

XXV. The forms of crystals obtained from solutions are, in many instances, varied according to the degree to which evaporation has been carried. Sal ammoniac may be procured in long four sided pyramids; but if a large proportion of the water have been vapourized, it will appear in the form of feathery crystals, composed of hexaedral pyramids. Corrosive sublimate appears in the form either of quadrangular prisms, or of plumose crystals; and nitrate of lead may be made to assume the figure of the octoedron, the tetraedron, the cube, or the four or six sided prism. In general, however, crystallized bodies affect certain forms, by which they may at once be recog-

* Essay on Chemical Statics, vol. i. note 14.

nized. Common salt crystallizes in cubes, nitre in long six sided prisms, alum in double four sided pyramids, applied to each other by their bases, and green vitriol in rhomboidal prisms. Diversity of figure seems to takes place in a greater degree in native crystallized bodies, than in those which are the products of art. No salt, with which we are acquainted, approaches in the number of its forms, the native carbonate of lime the calc spar of Mineralogists.

XXVI. The original form of a crystal is often so enveloped in particles of the same nature as to be obtained only by mechanical division. Bergman appears to have been the first to suspect that crystals might contain nuclei, differing in figure from those which are usually presented.* The idea was afterwards amplified, and, in some degree systematized, by M. Romé De Lisle.† But science is indebted to M. Haüy for the complete demonstration of the structure of crystals.‡ From the researches and discoveries of this philosopher, it seems, that in every crystal there exists a nucleus, for the most part differing in form from that in which it is enveloped, and that it may be exposed by sections made upon the faces, the edges, or the angles of what has been termed the secondary form. Thus it was found that the equilateral six sided prism, and the double six sided pyramid of calc spar, or carbonate of lime, might be reduced by successive sections to the rhomboid. This rhomboid then is supposed to constitute the nucleus of these crystals, because, when this figure is once developed, mechanical analysis is terminated, and no other form can be produced. Hence, the figure to which, in pursuing this method, the Crystallographer ultimately arrives, has been called the *primitive form*; and according to M. Haüy, the number hitherto observed, amounts to six. 1. The regular tetraedron. 2. The parallelopipedon, which includes the

* Opuscules Chimiques, tome ii. p. 1.

† Abbé Bucé. Nicholson's Journal, vol. ix. p. 26.

‡ Traité De Mineralogie, t. prem; and Elem. of Natural Philosophy. Eng. Trans. vol. i. p. 75.

cube, the rhomboid and all the solids which have six faces parallel two and two. 3. The octoedron, the surfaces of which are triangles and, according to the species, equilateral, isosceles, or scalene. 4. The hexaedral prism. 5. The dodecaedron with rhombal faces. 6. The dodecaedron with triangular faces.

The primitive forms are likewise supposed by M. Haüy to be susceptible of division and of being resolved into bodies having figures still more simple. Thus, the six sided prism may be converted into six three sided prisms; and the dodecaedron with rhombal planes may be inferred to be divisible in lines parallel to its different faces, by causing the cutting planes to pass through the centre and the result will be the formation of twenty-four tetraedra. To these forms which result from supposed sections of the primitive, has been applied the name of Integrant particles, and they amount to three, viz. 1. The tetraedron. 2. The three sided prism. 3. The parallelopipe-don.

The secondary forms of crystals, or such as are usually exhibited by nature, are made to grow out of these integrant particles and primitive forms in the following manner. The particles first unite to produce the primitive form, and from this proceeds the secondary form by the application of successive layers of the integrant particles, parallel to its faces; which layers are called laminæ of superposition. The modification of figure is the consequence of the abstraction of one, two, or more rows or ranges of particles, from the planes, or angles of each of these laminæ, by which a decreasing series of particles will be formed. Thus, supposing that upon one side of a cube, successive layers of cubic particles be placed, and each layer be less, by one range of particles, than the surface upon which it rests, it is obvious that the lines which bound the sides must be continually approaching each other, and, that finally, the last layer must consist of a single cube. It follows, then, that a four sided pyramid will be raised upon one of the surfaces of the cube; and that, if the same thing

happen upon the five other sides, the cube must be converted into a dodecaedron, with rhomboidal faces. The last figure is then secondary ; its formation has generally been quoted to illustrate the law of *decrement*, as it has been termed, and it is easy to represent it, although coarsely, by models. “ But if,” says M. Haüy, “ for this kind of rude masonry, which, however, has the advantage of speaking to the eyes, we substitute the infinitely delicate architecture of nature, it will be necessary to conceive the nucleus as consisting of an incomparably greater number of imperceptible molecu^{læ}, and then, the number of laminæ of superposition being itself considerably augmented, while their thickness has become imperceptible, the channels which these laminæ form at their edges will likewise escape our senses.” Hence the surfaces of crystals appear to us planes.

The facts which have been discovered relative to the laws of decrement, are sufficient to prove that an immense variety of crystals may be made to grow out of the combinations of the three integrant particles, and the six primitive forms ; for the decrements may take place, 1. on the edges, or parallel with the faces of the primitive forms, 2. on the angles, in which the lines are parallel with the diagonals of the faces, 3. in lines parallel to those which intersect the diagonals and faces, constituting the intermediate decrements, 4. or in a mode which combines more or less the decrements already mentioned, and which is therefore said to be mixed. These primary decrements may be so modified as that they shall take place on certain edges or certain angles only ; or in uniform and alternate ranges ; or from one edge or one angle to another ; or at the same time on all the edges and all the angles, &c. “ Nevertheless, such is the fecundity allied to this simplicity, that when limited to ordinary decrements and to four ranges on the edges and angles of a rhomboid, it may be demonstrated that this species of nucleus is susceptible of producing 8. 388, 640 varieties of distinct forms.”

XXVII. The conclusions to which M. Haüy has arrived during his investigations into the subject of crystallography are not merely speculative. By identifying the primitive forms of different crystallized substances, he has been enabled to state their connexion, and probable agreement in composition, before they have been demonstrated by chemical analysis; and, in cases in which these forms have varied, the subjects have been separated into distinct species, although the chemist could find no difference in the nature, or proportions of their elements. Yet, as the art of analysis has been improved, a more intimate knowledge of the composition of such bodies has confirmed, in some instances, the correctness of the deductions of the crystallographer. In fact, in M. Haüy's system of Mineralogy, the primitive form, or molecule is made the type of the species; and this principle has been applied with great ingenuity and, certainly, with unexpected success, to the classification of the subjects of this science. The researches and discoveries of Mr. Daniell also promise much support to this system; for, by his method the forms of amorphous, crystalline bodies may be successfully developed, and, consequently, it must contribute to remove one of the most material objections which have been urged against the arrangement of the French philosopher.

Mr. Daniell has found that when an amorphous mass of alum is suspended in water, the quantity of which is not sufficient to produce complete solution, and it be allowed to remain undisturbed for some weeks, the mass will gradually assume a pyramidical form, and the lower portion will present the forms of octoedrons and sections of octoedrons, as it were, carved or stamped upon its surface. These figures will be high in relief and of various dimensions. Suppose the piece of alum to be of a lengthened form, and that its length is in the direction of the axes of the octoedrons, of which we may conceive it is composed. If it be held in a horizontal position before the light, with one end towards us, the reflection will arise from the right angled parallelograms and the fig-

ures of the same class. If it be turned upon its axis 45° , the light will again be reflected from similar figures and twice more at the same relative distance, till we arrive at the face from which we set out. Instead of holding the mass horizontally, let it be inclined at an angle of 60° . The octoedra faces will then come into view. Upon turning it again from right to left as before, a similar repetition of these faces also will be perceived at intervals, corresponding to the right angled crystals, that is at every quadrant of the turn.*

The same effects were produced upon borax, which exhibited sections of eight sided prisms; upon blue vitriol, which was reduced to prisms terminated by rhombic faces; upon epsom salt, which presented sections of four sided prisms and low four sided pyramids; and upon nitre, the resulting figures of which were six sided prisms and six sided pyramids, forming by their intersection the triangular dodecahedron. In these cases of partial solution, the surface of the mass is not equally acted upon by the liquid; the upper part will be dissolved in larger proportion than the lower, for a very obvious reason.

The same effects are produced by a more complicated action. Thus a crystal of carbonate of lime immersed in vinegar, becomes marked, after a few days, with lines which present the primitive rhomboid: and the carbonates of barytes and strontian by the same method afford hexaedral prisms. Bismuth, in nitric acid, gives cubic figures; antimony, rhomboidal plates; and nickel, regular tetraedrons. Quartz, exposed to the action of fluoric acid, exhibits well defined lines, corresponding with the form of the primitive rhomboid of that mineral.

In order to obtain satisfactory results, it is obvious that when water is employed, it should bear a certain proportion to the crystalline solid. This proportion will be just, when the attraction of cohesion and the chemical force, are nearly balanced. If acids be used, they should be much diluted, and even then, well defined forms are developed with some difficul-

* Plate iii. fig. i. and ii.

ty, in consequence of the continued action of the streams of minute bubbles of air, which, in rising to the surface, pass over the sides of the solid and form channels.*

XXVIII. If we suppose with some of the Ancients, and with Sir Isaac Newton, that matter has a substratum and does not consist, according to the refined speculations of some philosophers, in spheres of attraction and repulsion, it will follow that it is composed of solid, impenetrable and indestructible atoms or particles. In the formation of crystallized bodies, these particles must unite in a certain mode, to produce the symmetrical solids; and the question may be asked, what form of atoms is best adapted to this purpose? We have no direct means of deciding this question, but it is possible to approximate to the truth indirectly by geometrical calculation. It has been shown by Dr. Wollaston and others, that the structure of crystals may be explained upon the supposition, that their elements, or atoms, are spheres, or spheroids.†

Thus, four particles may compose the tetraedron; five the tetraedral pyramid; six the octoedron; eight the cube, and twelve the dodecaedron. The rhomboid may be converted into the octoedron by taking away a tetraedron from each of the acute angles.‡ Mr. Larkin has also demonstrated the manner in which the cube may be supposed to be formed of spherical particles, first from the tetraedron, and next from the octoedron.§ These views have been confirmed and extended by Mr. Daniell.¶ He has shown that the arrangement of octoedral particles, so ingeniously applied by M. Haüy, cannot be supported, but that the hypothesis of spherical atoms is sufficient to account for the geometrical forms of all crystallized bodies, and consequently for the irregular figures of all amorphous masses. The cube, however, is formed in a

* Journal of Science and the Arts, vol. i. p. 24.

† Philos. Trans. for 1813.

‡ Plate ii. and Explanation.

§ Annals of Philosophy for Aug. 1815.

¶ Journal of Science and the Arts, vol. i. p. 48, and vol. iv. p. 30.

manner somewhat different from that of Dr. Wollaston, and includes the octoedron. If sixteen spheres be arranged side by side upon a plane in the form of a square, nine others, placed in a parallel plane above them will roll into their interstices ; particles, thus brought into contact, are operated upon by two forces, gravity and attraction of cohesion, and in this instance the two powers will be coincident. If sixteen other balls be thrown upon these, four only will arrange themselves in the interstices between the particles of the second layer by the action of gravitation ; while the remainder, operated upon by attraction, would place themselves with their centres immediately over the centres of the first layer. In this way by the successive addition of new layers the cube may be perfected ; and Mr. Daniell has very satisfactorily demonstrated the forms which may be produced from this figure, considered as the integrant particle.

Upon the causes which may determine the forms of solids as they are deposited from solutions, Mr. Daniell remarks, “ none would appear to have greater influence than the number of particles which are at once freed from the power of any solvent, and brought within the sphere of mutual attraction.”

“The first impulse is derived from a compound attraction of a certain number of molecules for each other, prevailing over the attraction of the fluid. The action is kept up by a disposing attraction which directs the subsequent deposition to certain points of the first formed nucleus. As one sphere cannot come in contact with more than twelve other similar spheres, the compound attraction must be limited to that number. If the number should exceed this, the nucleus will no longer be regular. This then is the boundary between symmetrical and amorphous crystallization ; and the greatest number of particles in the former arrange themselves in a hexaedral figure, the form which includes the greatest capacity under the least surface.”

SECTION II.

Affinity, or Chemical Attraction.

XXIX. The second species of contiguous attraction is that to which has been applied the name of affinity. This power operates upon heterogeneous substances and, in bringing their particles into contact, produces bodies, the properties of which are more or less different from those of their elements. The phenomena, classed under the head of affinity, may be considered in two points of view; first, in relation to those cases in which the attraction of the different bodies for each other is apparently feeble, the union they form is far from being intimate, and the change of properties is rather mechanical than chemical; and secondly, in regard to other instances, in which the mutual affinities are powerful, and result in the formation of compounds, whose elements always bear certain ratios, or definite proportions to each other.

XXX. To the first kind of affinity has been given the name of Solution. When a crystal of salt, or of sugar is put into water, its volume gradually diminishes, and after a certain time it disappears. It is then said to be dissolved, and the water is called the solvent. The effect is produced by the mutual attraction of the liquid and the solid. In these instances, the change of properties appears to be limited to that of form; for the taste and odour of the substance thus dissolved, and its affinities for other bodies are apparently unchanged.

Solution is promoted by agitation. If a coloured crystal, for example, of blue vitriol, be dropped into a tall glass jar filled with water, and it be allowed to remain undisturbed, its solution goes on slowly, the water immediately in contact with it becomes coloured, the tint of blue increases upward very gradually, and an uniform colour is not produced in the whole of the liquid for several weeks. If the vessel were constantly exposed to the same temperature, it would for this effect probably require several months. By constant agitation, the same uniformity of diffusion might be produced in a few minutes.

After the solution of a body has taken place, it appears to be equally diffused through the solvent, and a portion taken from the surface will yield by evaporation the same quantity as an equal weight of the liquid taken from the bottom. The power then which causes solution is superior both to gravity and to the attraction of cohesion.

The proportion in which a soluble substance is dissolved, is dependent upon temperature. There are few exceptions to this generalization. Common salt, however, it is well known, is very nearly equally as soluble in cold as in hot water. At a given temperature, when a liquid will dissolve no more of a solid, it is said to be *saturated*. The amount of a great variety of salts &c. dissolved by water and other liquids at certain temperatures, e. g. at 60° , and at their boiling points, has been ascertained with precision; but no experiments have yet been made, I believe, to determine the ratio of the solubility at all the intermediate degrees. The degree of heat being determinate, the proportion of the salt dissolved is always definite, and it is altered only by change of temperature.

Of the salts, the deliquescent are the most soluble; next to these are the compounds, which contain the largest proportion of water of crystallization, and the least soluble are the *anhydrous* salts, or at least those which do not yield much water.

The density of a saturated solution is greater than the mean of the liquid and solid separately considered.

There are some instances in which this kind of union is indefinite. Isinglass or glue may be dissolved in water in all proportions; spirits of wine and the strong acids, such as oil of vitriol and aqua fortis, may be indefinitely diluted with water and yet preserve a uniformity of diffusion in the liquid, one portion exhibiting the same degree of strength as another. These have therefore generally been considered as examples of affinity.

XXXI. M. Berthollet and some others have considered the union of water with air, and the absorption of airs by li-

quids as a species of solution; and the first has given to this kind of action the name of Dissolution. The theory of Dr. Halley, which was supported by Le Roy, Hamilton and Franklin, of the cause of evaporation, has been strongly opposed; and we shall show, hereafter, that the opinion of M. Berthollet, on this subject, has been controverted and perhaps disproved by Mr. Dalton.

XXXII. It has been supposed that the phænomena of solution depend upon the operation of the same power which, in other circumstances, produces the effects of more intimate combination. But the recent discoveries in this science, and the difference perceived in the results of these actions, may, perhaps, lead to the suspicion, that the cause of solution is rather mechanical than chemical. Solution, so far as we can perceive, is a change merely in the state of aggregation of the particles of bodies. The physical qualities, such as taste, odour, &c. remain the same; and the affinities are rendered more effective and, consequently, are apparently multiplied, only because liquefaction has removed a state of cohesion, which operates as an antagonist power to chemical affinity. Water and other solvents appear to act merely in giving mobility to the atoms of the bodies which they dissolve; and, from the condensation, or increase of density, which accompanies this change, it may be inferred, that a mutual penetration of the particles takes place. No farther union perhaps is occasioned, than that which might be supposed to happen, when the atoms of water ascend in porous bodies above the level of the liquid, in which these bodies are partly immersed. Experiments however are still wanting to develop the true nature of solution, and to define the immediate cause upon which its phænomena are dependent.

XXXIII. When potash in a certain proportion is immersed in nitric acid, diluted with water, its bulk rapidly diminishes, and in a short time it disappears. On evaporating the liquid to a certain degree and allowing it gradually to cool, well defined six sided prisms will be deposited, and these, on

examination, may be proved to consist of the acid and potash. It is evident, then, that these two substances have an affinity for each other, and that when sufficiently near their particles *combine* and form a chemical *compound*. This kind of action is very different from that which occasions solution; the particles of potash are not merely diffused through those of the liquid acid and still capable of producing the specific effects of that substance; but they apparently disappear, and we have, instead, a salt, which exhibits very different properties. This one example illustrates the general fact, that it is a characteristic of chemical affinity to produce bodies, which differ in their qualities from those of the elementary substances, of which they are composed. In a multitude of instances this difference is so absolute, that the parts of a compound can no longer be recognized by the senses, nor identified in any other way, than by again separating them from each other. Thus, if sulphur and mercury be triturated with each other, and afterward be exposed to heat in a close vessel, a compound will be formed, which rises in vapour and condenses upon the upper surface in the form of a dense crystallized cake of a red colour; and this mass, by subsequent manipulations, which however do not affect its composition, is converted into the vermillion of commerce. The product arising from the combination of inodorous substances is often acrid and corrosive. Sulphur, while burning in the open air, acquires a pungent and suffocating quality. Sapid bodies are converted into others, which are either insipid, or have a taste entirely different from that of either of the ingredients. Gypsum, or plaster of Paris, is altogether tasteless, yet it is composed of two corrosive substances. Epsom salt is bitter, although one of its constituent parts is sour, and the other nearly insipid; and the salts of Glucina are sweet, notwithstanding the only substance contained in them, which has taste, is an acid. The medicinal properties of bodies are equally varied by their chemical combination. The poisonous quality of arsenic is exceedingly diminished by its union with sulphur; metallic mercury has

no apparent action, except from its gravity, upon the human system, yet when combined with oxygen, or chlorine, it is known to operate as a strong stimulant upon the living fibre; and Glauber's salts may be used with impunity, although the substances, of which they are composed, act, in their pure and concentrated state, with the rapidity of caustics.

Change of form is another circumstance which frequently accompanies the exertion of chemical affinity. Two airs are condensed into a liquid, and sometimes into a solid, during their combination. Oxygen and hydrogen gases, as they unite, form water; and sal ammoniac results from the combination of gaseous ammonia and muriatic acid. Two liquids may be made to form a solid, and two solids, by their mutual action, produce a liquid.

Change of properties, therefore, is characteristic of chemical affinity; but it does not follow, that the properties of a body, thus formed, should partake, more or less, of those which belong to one or both of its constituents. This in fact does not appear to be the case, and some of the examples, just cited, prove the truth of the observation.

XXXIV. Next to change of properties, a variation in the temperature of bodies, during chemical action, is the most common accompaniment. The degree of heat is either increased or diminished, according to the circumstances of the experiment and the nature of the bodies. In the largest number of cases, the temperature is augmented. Combustion is a familiar example of large quantities of heat produced by chemical action. It is also evolved in the processes of fermentation and respiration. If oil of vitriol be poured upon quicklime, the temperature will soon rise above the 600° of Fah. and when strong aqua fortis is added to about an equal bulk of spirit of turpentine, the mixture will generally burst into a flame. In some examples of the loose combination which has been considered as analogous to solution, the same phænomenon is observed. Equal bulks of strong spirit of wine and of water, when mixed and agitated, produce a

rise of temperature of several degrees ; and equal weights of concentrated oil of vitriol and water cause by their union a degree of heat equal to the 260° of Fah.

In other cases the temperature falls and it is found to take place whenever the density is diminished, as in the passage of a solid to a liquid and of a liquid to a gaseous fluid. Thus powdered nitre, while dissolving, will sink the temperature of the water 17° ; equal weights of this salt and sal ammoniac 28° ; and a mixture of dry snow with the salt called muriate of lime, in proper proportions, reduces the temperature below the freezing point of mercury.

XXXV. It has been inferred as a general principle, that in all cases of chemical combination, in which there is a condensation of the elements, the temperature rises ; and that it falls whenever the volume is augmented ; or, more generally, that if the density be changed, the temperature will also be affected. On this principle the production of heat in combustion, fermentation, respiration, and in the animal body ; in the combinations of oil of vitriol with quicklime and with water ; and the reduction of temperature in solution have been explained. But there are many facts irreconcilable with this doctrine. All the solid explosive compounds evolve much heat during their rapid action. The fact is familiar with regard to gun-powder ; it is also the case with fulminating gold and silver, and yet the explosion of these compounds produces permanently elastic fluids. The liquid compound discovered by M. Dulong, and called *chloride of azote*, is decomposed, in certain circumstances, with great violence and with the production of heat and light, notwithstanding that by this action it is reduced to its elements, which are two elastic fluids. The same thing happens with a compound air called *euchlorine*. Now, in these cases, the density of some, or of all the elements is diminished and, according to the principle laid down, the action ought to be accompanied by reduction of temperature. M. Gay Lussac has given several examples of the same kind, which go to prove that the production of

heat is not necessarily the consequence of increased density. In fact, wherever chemical combination or decomposition is rapid, or wherever bodies exercise powerful affinities for, and combine energetically with each other, heat and often light become perceptible.

XXXVI. The effective force of chemical affinity is influenced, 1. by Cohesion ; 2. by Temperature ; 3. by Elasticity ; 4. by Quantity of matter.

XXXVII. *Cohesion.* The more strongly the particles of a body cohere, the less power have they to combine with those of other matter. Cohesive attraction may therefore be considered as an antagonist power to chemical affinity. Hence arises the necessity of weakening this power, in many instances, before the elements can enter into new arrangements. The form of bodies best adapted to enable them to combine, generally speaking, is that in which their particles have freedom of motion, but are retained to each other by a loose aggregation, such as exists in liquids ; and the necessity of this mobility is, in many cases, so apparent, that at one period it was considered as an axiom in chemistry, that bodies will not act unless at least one of them be in a fluid state. The dry powders, which are frequently sold here for the purpose of producing soda water extemporaneously, are mixtures of tartaric acid and the soda of commerce. In this state they do not act upon each other, but if put into water, they dissolve and immediately exercise certain affinities. There are, however, so many cases in which solids mutually operate and give rise to new compounds, that the propriety of the generalization may well be questioned. Thus, for example, dry lime and sal ammoniac, alum and sugar of lead, salt and snow &c. act chemically, notwithstanding they are in a solid state. Mr. Link has found that salts, which if liquid readily decompose each other, produce the same effect by being triturated together in a solid state, provided they be crystallized. Thus sugar of lead and blue vitriol both in crystals mutually operate upon each other, but if the vitriol be previously deprived

of its water of crystallization, no effect will follow their trituration. Sugar of lead and alum, it has long been known, assume the consistence of paste when rubbed together, but if burnt alum be employed, the two salts remain inactive. From these and a variety of other experiments this chemist concludes, that the trituration of anhydrous bodies, i. e. bodies destitute of water, produces no chemical action, but that the water of crystallization acts as free water and consequently as a solvent.*

When the particles of bodies are strongly coherent, they are acted upon with great difficulty, notwithstanding that when loose they are soluble in acids, &c. and hence it is, that the tin stone, the ruby, sapphire, and adamantine spar, in their crystallized state, may be exposed to the most active agents without undergoing any perceptible alteration; while, if previously reduced to fine powder, their elements may be readily separated and their composition be accurately determined. Fluidity has the effect to separate the particles of bodies and, as a force more or less energetic, operating against the power of affinity is thus removed, such particles are in the most favourable state for effecting this combination.

XXXVIII. It cannot be supposed, however, that because cohesive attraction has been overcome by a superior force, it should be considered as destroyed. The tendency of the particles again to unite must still exist and it must become effectual so soon as the opposing force is removed. There may be a certain stage of solution, in which the balance between the two powers is such as to prevent the process from advancing, although mutual saturation has not taken place. This is the opinion of M. Berthollet, and he further insists that, in new combinations, it may become an active power, may determine the proportions and produce depositions, or crystallizations, by withdrawing the body formed by its exertion from the action of the solvent and, to a certain extent, limiting its power.†

* Annals of Philosophy, vol. viii. p. 429.

† Researches into Affinity, Art. v. and ix.

XXXIX. *Temperature.* The well known property of heat to lessen the cohesion of the particles of bodies, might lead us to expect that it would favour their combination, and this is the fact to a certain extent. The aggregation of the particles of solids is an obstacle to their union, and in them the application of heat produces the same effect as solution in a liquid. The particles acquire mobility and the power of exercising their mutual affinities. It frequently exerts the same influence upon liquids; but upon the elastic fluids, or airs, it operates in a different manner; for their particles being already endowed with a repulsive energy, it must be increased by their exposure to an high temperature, and their atoms must be removed still further from the spheres of their mutual attraction. The effects of heat, therefore, in favouring the exercise of affinities, depend upon the forms of matter and the nature of the compound. If, says M. Berthollet, the substances be equally fixed; or if they be not all in the liquid state; or if one of them be soluble only to a slight degree, heat will favour their mutual action by diminishing their force of cohesion, which acts even between liquid parts.* But if a body be composed of two ingredients, one of which has a disposition to assume the elastic form, while the other is less susceptible of volatility, the tendency of the former to take on the gaseous state, may, beyond a certain temperature, become so great as to overcome its affinity for the latter, and they will consequently separate. In some compounds the balance of affinities is so delicate, or their elements are united by so feeble a force, that a moderate increase of heat is sufficient to alter the one, or decompose the other. Of the former cases, the metallic fulminating solids are examples, and of the latter, eucchlorine and the detonating compound of M. Dulong.

XL. Heat then may be employed to facilitate the union of two or more solids, or a solid with a liquid, or a solid with an elastic fluid. It is well known that two metals must be melted, or at least that the cohesion of particles in one of them

* Researches, p. 53.

must be overcome, before they will combine. Glass is the product of the fusion of two or more solids ; and, in almost all cases of this kind, the fusibility of the compound is greater than that of its constituent parts. In these instances, it appears to operate in lessening the effective force of cohesive attraction ; and hence, also, may be explained its influence, not only in accelerating solution, but likewise in augmenting the proportion of the solid which may be dissolved.

When a solid substance and a gaseous fluid are to be united, it generally happens that it is necessary to raise the temperature to a certain degree before the combination will commence, after which the heat, produced during this union, becomes sufficient to continue the mutual action. This is the case with regard to the reciprocal action of oxygen, with sulphur, phosphorus, charcoal, &c ; and even where a gaseous fluid will combine with a solid at common temperatures, as, for example, oxygen with many of the metals, the same combinations are produced in a much shorter time by increasing the heat of the solids.

XLI. This agent produces the same effect upon mixtures of the elastic fluids which exert mutual affinities. An iron wire heated to whiteness and plunged into a vessel containing the two airs called oxygen and hydrogen, will produce an explosion and the formation of water. The same result is obtained by the application of a flame to the mixture, and by electricity. It cannot however in this example be supposed, that temperature operates by diminishing cohesion ; for it does not exist. It is more probable that in many instances heat favours combination, by exalting the mutual affinities of bodies and thus increasing their tendency to unite.

XLII. But if heat be often employed by the chemist to cause the union of bodies, it is likewise sometimes made use of for the purpose of reducing them to their elements. Many liquids are decomposed by transmitting them, in the form of vapour, over the surface of ignited glass, porcelain or metal ; and this effect will take place even where one of the constitu-

ents in its uncombined state is solid. Compound airs by the same process may be resolved into two, or three simpler forms of matter; and the same result is obtained from the vapours of volatile solids. Here the action of heat may be considered as opposed rather to the force of affinity, than to the attraction of cohesion.

Hence, in all cases in which this opposition is perceived, it is obvious that by lessening the power of heat, we virtually increase the effectiveness of affinity, and, therefore, in producing solutions, as they have been termed, of elastic fluids in liquids, the effect is proportional to the degree of cold, or the reduction of temperature to which the bodies are exposed. It has been found that water at the temperature of 40° will condense a larger volume of fixed air, of ammonia, or of the acid elastic fluids, than at 60° ; and that, if to such solution heat be applied, the substance thus condensed will reassume its elastic form, or the solution will become proportionably weaker.

The effects of this power, therefore, upon chemical affinity depend upon the nature and forms of bodies; and upon its operation in weakening cohesion, increasing the tendency to elasticity, and, probably, exalting the force of chemical attraction.

XLIII. Elasticity. This property being opposed to cohesion, might be supposed to act in favouring combination; but the distance to which the particles of elastic fluids are mutually repelled, presents an obstacle to their action. Hence when simple gases are mingled with each other, or with some of the compound elastic fluids, they become uniformly diffused, but do not present the phænomena of chemical union. Oxygen and nitrogen, hydrogen and nitrogen, hydrogen and oxygen, have respectively an affinity for each other, but when they are mingled, neither nitric acid, nor ammonia, nor water is formed. To produce these compounds it is necessary, either to augment their force of affinity by heat, or electricity, or to present one of the constituents to the other in a form

in which elasticity can have no influence. When two elements are combined, and the product exists in the state of air, the body discovers a greater tendency to union with other compound gaseous matter, than is exhibited by either of its constituents ; and, in cases in which such airs offer opposing properties, the elastic state seems to afford no obstacle to the effectual exertion of their affinities. Such, for example, are ammonia and the acid gases.

XLIV. Among the vapours, in which the elasticity is not permanent, and the bodies are not far removed from the point at which they become liquids, combinations are more readily produced than between the gases ; and where affinities exist, they are more effectually exerted between a solid, or a liquid and an air, than where both are in the elastic form. In these instances, heat often operates to facilitate the union by lessening the cohesion of the particles of the solid ; and more, it has been supposed, is gained by this diminution of aggregation, than is lost by the increased elasticity acquired by the air. Yet the tendency of the basis of the air to reassume its gaseous state is often such, as to become effectual at a temperature somewhat higher than that, at which the compound is formed. Thus, mercury, if exposed when near its boiling point to the influence of atmospheric air, attracts its oxygen and forms a compound ; but the elements of this compound may again be obtained by heating it some degrees higher than that which was necessary for its formation. It has already been observed, that pressure operates in causing elastic fluids to combine in larger proportion with liquids, and the effect is produced by the approximation of the particles, and the consequent reduction in volume. Pressure will even prevent the disengagement of an elastic fluid from a compound, although it be exposed to a degree of heat which, in ordinary circumstances, would be sufficient to effect it. Thus, chalk is a compound of lime and carbonic acid, the last of which leaves the lime and becomes a gas at a red heat ; but, it was found by Sir James Hall, that by heating chalk under

great pressure, it was melted and acquired the crystalline texture of marble, the carbonic acid being retained.

XLV. *Quantity of matter.* M. Berthollet has proposed and strenuously defended the doctrine, that affinity is influenced by the quantity of matter; that this action is in the ratio of the attraction and the acting masses of the bodies exerting it; and that the feebleness of affinity may be compensated by a proportional increase of the quantity. This view of affinity has also been adopted by Dr. Murray and M. Thenard. There are many experiments, the results of which favour this conclusion. Thus, if sulphate of baryta, phosphate of lime, carbonate of lime, or oxalate of lime be boiled in water with an excess of pure potash, an examination of the results of the action will show the presence of sulphate, phosphate, carbonate, or oxalate of potash; if nitric acid be boiled with oxalate of lime, one of the products will be nitrate of lime; and sulphate of soda may be formed by treating in the same way, sulphate of potash with pure soda. In all these instances, the proximate elements of the compounds, that is to say, the acids and bases, are said to have stronger mutual affinities than are found to obtain between the acids and the third body added. Yet, according to M. Berthollet, the potash being in excess, its quantity compensates for its inferior affinity, and the acids are shared between the two opposing bases in ratios proportional to their attractions and acting masses. Whence it follows, that the greater the relative quantity of the third body, the more decided must be the effect, and, consequently, that if the new compound, which has been formed, be removed and fresh portions of potash added, the whole of the salts above mentioned may be decomposed. Other examples have been brought forward, to prove the correctness of this doctrine. Lime, says M. Berthollet, can deprive carbonate of potash only of a part of its acid; sulphuric acid cannot completely disengage phosphoric acid from phosphate of lime; nor can liquid ammonia, when poured into solution of alum, precipitate its base free from sulphuric acid, nor pot-

ash entirely decompose sulphate of magnesia. In all these cases, this excellent chemist affirms that a partition of the acids between the two bases takes place, proportional to the energy of their affinities and their quantities of matter.* It follows, from this view of the subject, that the chemical action of one body on another must be diminished in intensity as it becomes saturated; because a proportional quantity may be considered as having its power neutralized; and that when the combined affinity and quantity of the body come to equal the attractions of the elements of the compound, the action must cease.

XLVI. The facts thus stated and the conclusions adopted by M. Berthollet, if just, necessarily lead to the belief, that affinity is not a constant and invariable power, operating alike in all circumstances, and combining bodies in uniform and definite proportions, but that it is so modified by cohesion, heat, elasticity, insolubility, quantity of matter, and other accidents, that the relative force in the affinities of different bodies can hardly be estimated, if indeed they exist. The experiments of M. Berthollet, when strictly examined, seem hardly to warrant the conclusions which he has drawn. With regard to the first, in which potash is said to have decomposed sulphate of baryta, the fact is denied by Sir H. Davy.† The decomposition may be effected by carbonate of potash, and as the materials during the experiments just stated were exposed to the air, the potash probably attracted carbonic acid from the atmosphere and formed a carbonate, which reacted upon the compound with which it was mixed. The decomposition of the salts of lime may perhaps be satisfactorily explained on the same principle, and there appears nothing to the contrary in M. Berthollet's experiments, as it is not stated in what form the lime appeared at the conclusion of the processes. Soda separated sulphuric acid from potash; but the result of this experiment, which was supposed to furnish a proof of the influence of quantity, is thought by Sir H.

* *Researches into the laws of affinity*, p. 8. et seq.

† *Elements of Chem. Philos.* Part i. p. 119.

Davy to* be produced by the affinity of the potash for the water contained in the soda; and he also affirms, that if the magnesia, which is separated by an alkali from epsom salts, be well washed with water, it affords no indication of sulphuric acid. The experiments of Mr. Pfaff, as quoted by Sir H. Davy, confirm these conclusions.

XLVII. If affinity be modified by quantity, it must happen that all chemical analyses will be exposed to the uncertainty of producing mixtures, or compounds containing variable proportions of the substances employed, that "salts crystallizing in acid solutions will be acid, and alkaline, in alkaline solutions." But this does not appear to be the case, and although M. Berthollet, from such solutions, obtained salts with variable proportions of acid, yet, as it is well known that the fixed alkalies combine in two proportions with some of the acids forming two distinct compounds, it is most probable, that the salts thus obtained, e. g. those of potash and sulphuric acid, were a mixture of the sulphate and the bi-sulphate.

After all, even supposing the fact established, that the attractions of bodies are in the ratio of their affinity and quantity, there is nothing in the law which can be supposed incompatible with the fact, that bodies combine in definite proportions; for if potash decompose sulphate of baryta, the sulphate of potash thus formed, contains the same proportion of the base and of the acid, as exists in the sulphate produced in the usual way. When soda was boiled with sulphate of potash, M. Berthollet obtained a "considerable quantity of crystallized sulphate of soda,"* and we have no right to conclude that this sulphate differed in any respect from common Glauber's salts. Potash was converted into a carbonate by being boiled with carbonate of lime. It probably acquired one proportion of carbonic acid and formed the sub-carbonate or pearl-ash. There appears no difficulty, says Mr. Davy, in reconciling the doctrine of definite proportions with the influence

* *Researches*, p. 11.

of quantity ; none of the experiments of M. Berthollet can be considered as strictly contradictory to the doctrine, and some of the most important results of this sagacious chemist afford it confirmation.

XLVIII. It is a conclusion, founded upon the opinions of M. Berthollet, that where a decomposing power operates upon a compound, one of the elements is separated only to a certain extent ; that in proportion as the quantity becomes less, the remainder is retained by a stronger affinity, which at length becomes so energetic, as to balance the force exerted to disunite the substances composing the compound ; and, consequently, that the decomposition ceases before it has become complete. But this law appears to be limited to those cases in which one body is combined with two or more proportions of another. From such compounds it is comparatively easy to disengage the second or third proportion. Thus, the metal manganese is found combined with two definite proportions of oxygen. By exposure to a red heat one proportion of the oxygen may be evolved ; but no degree of heat, which can be excited in a furnace, is sufficient to drive off the other proportion ; carbonate of soda is decomposed with facility by heat, yielding one half of its carbonic acid, but the other half is retained with obstinacy. Dr. Wollaston found that at a high temperature, carbonate of potash gave out a quantity of carbonic acid, and that the remainder, treated by an acid, produced the same bulk of that gas. “Nitric acid is easily brought to the state of nitrous gas by the abstraction of oxygen ; nitrous gas with more difficulty is converted into nitrous oxide ; but nitrous oxide is still less decomposable than nitrous gas.”* Hence it appears that when one body is combined with more than one proportion of another, the higher proportions are more easily separated than the first ; and some of the experiments, which are said to demonstrate the influence of quantity, may be explained, partly on this principle, and in part on the fact, that some bodies have a tendency to unite with more than one proportion of another.

* Davy's Elements of Chem. Philos. Part i. p. 116.

Compounds containing more than one proportion of one of the constituents, enter also into combination with other bodies with less facility than when they consist only of one proportion of each. Sulphuric acid does not act upon the bi-sulphuret of iron, nor upon the black oxide of manganese. The peroxide of potassium gives off oxygen when it comes into contact with water, and sulphuretted hydrogen, when formed at a high temperature, deposits, as it cools, a portion of its sulphur.

XLIX. It sometimes happens that two bodies which have apparently no affinity for each other, may be united by the intervention of a third. If iron filings be immersed in water, no immediate action takes place between them ; but, upon the addition of sulphuric acid, a brisk effervescence commences, which is accompanied with the production of an inflammable air. Phosphorus alone will not decompose water, but if it be boiled with water, containing a large proportion of pure potash, the elements of the liquid will be separated apparently with ease. Now, in these cases, the acid in the first experiment and the alkali in the second, dispose the iron and the phosphorus to decompose the water ; and hence, to this kind of action has been given the name of *Disposing*, or *Predisposing* Affinity. It has been found difficult to account, in a satisfactory manner, for the mode in which the action is suddenly increased in these instances. Iron is known to have a strong affinity for oxygen, and to decompose water, which contains this element, very slowly at common temperatures. Why should sulphuric acid cause this action to proceed with such increased energy ? M. Berthollet, who maintains the opinion that the properties of compounds partake of those of the elements which compose them, infers, that as an affinity exists between sulphuric acid and the compound of iron and oxygen, there must be an affinity likewise between the acid and oxygen ; and this affinity, aided by that of iron for oxygen, is superior to the power which unites the oxygen to the hydrogen to constitute an integrant atom of water ; the liquid is therefore decomposed.* But it does not follow, that,

* Researches, p. 136.

because oxide of iron and sulphuric acid are capable of uniting, there must also exist an affinity between oxygen alone and the acid. No metal, in its pure state, will combine with an acid, yet its oxides enter into union with it, with facility; we have no right to suppose that there is an affinity between the metal and the acid, for experiment has never demonstrated that this is the case. The old method of explaining this action involved the absurdity, that the acid facilitated the decomposition, in consequence of its attraction for the oxide, which was the product of the action. Dr. Coxe of Philadelphia supposes that the oxygen is derived from the acid, and that it is restored to the acid at the expense of the water.* There are, however, some formidable objections against this hypothesis. Sulphuric acid contains three proportions of oxygen, black oxide of iron, the compound formed in this experiment, two and water one proportion; if, therefore, the acid be partially decomposed and converted into sulphurous acid, by transferring one of its proportions of oxygen to the metal, it would not be sufficient to form the oxide; to produce this effect, it would also be required that two integrant particles of water be decomposed, the oxygen of one combining with the sulphurous acid, and that of the other with the iron. If the sulphuric acid give two proportions of oxygen to the iron, it will be converted into the oxide, but, in this case, the oxygen of two atoms of water must be transferred to the sulphur, and this mode of explanation gives to sulphur a force of affinity superior to that of hydrogen, a conclusion which is not warranted by experiment. The weakness of the affinity between sulphurous acid and oxygen, compared with the affinity which unites the elements of water, is such as to cause us to doubt whether such decompositions, as Dr. Coxe infers, can take place. The true nature of disposing affinity does not appear to be sufficiently developed.

L. If lime be added to diluted aqua fortis, its bulk will rapidly lessen and in a short time it will be dissolved. The product of this solution is a salt called nitrate of lime. When

* Observations on Combustion &c.

solution of potash is added to solution of this salt, the liquids become turbid, and lime is separated. The remaining liquid contains a salt, called nitrate of potash. In this experiment, it appears that potash takes the place of the lime, it combines with the acid, and is, therefore, said to have a stronger affinity for nitric acid, than exists between the acid and the lime. If into a second portion of solution of nitrate of lime, be poured sulphuric acid, a solid substance will be thrown down, which, on examination, may be proved to consist of the lime and the acid last added. Hence the mutual affinity of lime and sulphuric acid is superior to the affinity of nitric acid and lime. On the addition of solution of pure ammonia to a third portion of the first named salt, the mixed liquids will preserve their transparency, and exhibit no chemical change; whence, it is inferred, that ammonia has not so strong an affinity as lime for nitric acid. In the two first examples, the nitrate of lime is said to be *decomposed*. Experiments such as these demonstrate that, in given circumstances, the affinities of heterogeneous bodies for each other are unequal; that in some, they exist in a much greater degree than in others, and hence, that when a number of different substances, which are known to act chemically upon each other, are mingled, the actions that take place, and the combinations that ensue, will proceed in the ratio of the strength of their affinities. In cases in which a solid substance is separated, it is said in chemical language, to be *precipitated*. This difference in the forces of affinity has also been illustrated by the phenomena exhibited by metals in different metallic solutions; but the precipitation of silver by copper, of copper by iron, &c. most probably depends upon decompositions and combinations which should be referred to the influence of voltaic electricity.

LI. If the forces of affinity in different bodies be estimated by the order of their decompositions, it is obvious that when this order should be established by experiment, tables might be so constructed as to exhibit the affinity of one body for a number of others; an arrangement which could not fail

to be extremely useful to the practical chemist. Geoffroy, upon this supposition, formed in 1718 tables of this kind, on the following very simple plan.

Acids.	Fixed Alkalies.
Fixed Alkalies.	Sulphuric acid.
Volatile Alkalies.	Nitric “
Absorbent Earth.	Muriatic “
Metals.	Acetic “
	Sulphur.

In the first, the acids are placed above the horizontal line, and, immediately below it, the bodies for which they have an affinity; and the first is able to take the acids from all those which are beneath it. In the second, the Fixed Alkalies are at the head, and sulphuric acid having the strongest affinity for them is placed immediately below, next the nitric, &c. so that this order is intended to show the relative forces of affinity between the different acids and the alkaline bases. These tables were enlarged by succeeding chemists. But it was principally to the labours of Bergman on the subject of affinity, that we are indebted for a very complete series. This great chemist supposed that affinity was a definite force, acting with different degrees of energy in different bodies, and, consequently, capable of being represented by numbers. Whenever, therefore, a third body is added to a compound, for one of the constituents of which it has a stronger affinity than that which already exists, the latter will be decomposed, and the whole of one of its elements be transferred to the body added.* Hence, affinity was said to be *elective*, and decompositions, which took place among compounds, were thought to be complete. Thus, sulphuric acid and barytes have a strong attraction for each other, and if this acid be added to nitrate of barytes, a sulphate will be precipitated, and it was inferred that the whole of the base left the nitric to combine with the sulphuric acid. Bergman's tables exhib-

* Opuscules Chimiques, t. iii. p. 291.

it the relative affinities of different bodies in two ways, the *dry* and the *humid*, the former when the bodies are exposed to a strong heat and the latter when in a state of solution. The first of the following tables illustrates the affinities of silver in the dry way, and the last in the humid way, according to this chemist.

<u>Silver.</u>	<u>Oxide of Silver.</u>
Lead.	Muriatic acid.
Copper.	Sulphuric “
Quicksilver.	Oxalic “
Bismuth.	Sacchilactic “
Tin.	Phosphoric “
Gold.	Sulphurous “
Antimony.	Nitric “
Iron.	Arsenic “
Manganese.	Fluoric “
Zinc.	Tartaric “
Arsenic.	Citric “
Nickel.	Formic “

LII. Mr. Kirwan constructed tables of affinity upon the principle, that the absolute force, exerted by one body for a number of others, might be determined by the quantity of each required for saturation. The results of these were founded upon experiments conducted with great care and precision. He found that different acids required very different quantities of the salefiable bases for neutralization ; and the converse, that each base united with different quantities, by weight, of the various acids. Accordingly, by ascertaining the proportions in which these combinations were produced, he supposed that the numbers might express their relative powers of saturation, and the ratio of their affinities. Thus, if 194 parts of barytes and 118 of potash saturate 100 of sulphuric acid, the ratio of their attraction for the acid is as 194 to 118. The following tables exhibit the mode adopted by this chemist, as altered by Dr. Henry to accommodate them to recent discoveries.*

* Elements of Chemistry, vol.i. p. 52. 7th ed.

100 parts of Sulphuric acid re- quire for neutralization	100 parts of Potash require
194 parts of Barytes.	115 . . of Nitric acid.
138 . . . of Strontites.	93 . . of Carbonic "
118 . . . of Potash.	84.5 . . of Sulphuric.
78.2 . . . of Soda.	58 . . of Muriatic.
71 . . . of Lime.	
49.2 . . . of Magnesia.	
43 . . . of Ammonia.	

It will appear, on inspecting these tables, that the theory does not accord with facts. If the force of affinity be estimated by this mode, it is obvious that nitric and carbonic acids should have the power of decomposing sulphate of potash ; but it is well known, that sulphuric acid disengages these acids from the alkali ; ammonia also partially decomposes sulphate of magnesia, and its affinity for sulphuric acid is at least equal to that of magnesia ; but, according to Kirwan, it is inferior. Hence, the order of attractions, as stated, was so evidently in contradiction to many known facts relating to this subject, that the author of the tables found it necessary to assume, that the affinities of different acids for a base are inversely proportional to the affinity of the saturating acid. The difficulties, however, were not removed, and this method could not be adopted. M. Berthollet concludes, that the affinity of the different acids for an alkaline base, is in the inverse ratio of the ponderable quantity of each of them which is necessary to neutralize an equal quantity of the same base ; but, by proportioning the quantities to the affinity, they produce the same effect.* These deductions result from the laws which this great chemist attempted to establish, that, affinity is exerted in the ratio of the quantity and the attraction ; and that the properties of compounds are derived from those of their elements. Yet this mode of estimating chemical forces appears

* Essay on Chemical Statics, vol. i. p. 45.

not only to be arbitrary, but opposed to fact ; for, if it were just, ammonia ought to decompose all the compounds of sulphuric acid with the bases placed above it in the preceding table. But this is not the fact, nor would it happen, even if the quantity of the ammonia were added in great excess to compensate for the comparative feebleness of its affinity.

LIII. The doctrine of Bergman was considered as giving a just view of the subject of affinity, until M. Berthollet published the results of his profound researches. Instead of considering affinity as elective and constant in its force, he has endeavoured to prove that it is modified by quantity of matter, or that it acts in the ratio of the attraction and of the mass ; and, hence, that a substance which possesses a strong affinity is not capable of separating, completely, another which has an affinity less energetic, from a third body, but that the second is shared between the first and third, in the ratio of their affinities and acting masses. It follows, as a necessary consequence that, if this be a fact, there is no such thing as a complete decomposition. This opinion is derived from the hypothesis, that affinity is occasioned by the same power which produces gravitation, and that the energy of the attraction must be in the ratio of the quantity of matter, and dependent upon the form of the particles. Affinity, then, is attraction, and the result of its exertion must be combination, which may be in unlimited proportions. If decomposition take place, it must arise from the operation of other causes, such as insolubility, cohesion, elasticity, &c. Thus sulphuric acid causes a precipitation from nitrate of barytes, and potash from nitrate of lime ; in these cases, the decompositions are supposed by M. Berthollet to take place from the condensation, in the one experiment, of the sulphate of barytes, and in the other, of the lime, forming insoluble aggregates which are precipitated. Hence it appears that if cohesive attraction had not acted, the decomposition could not have been produced. The same view is taken of those decompositions in which one of the constituents assumes the elastic form. Hence, also,

although A may separate B from C, and form AB, yet reciprocally C may be made to decompose AB, and again combine with B, to the exclusion of A, or at least B will be shared between A and C in proportion to their affinities and acting masses. From this view, it has been inferred, that the affinities of a compound are made up of those of its elements.*

LIV. M. Berthollet has sufficiently demonstrated, that the hypothesis of Bergman is not always applicable; that affinity cannot, in all cases, be considered as an invariable force, and that the order of decomposition is not always the measure of the intensity of affinity. Yet, it is questionable, whether he has established his own. We have already adverted to the experiments which were supposed to prove the effect of mass (XLV.) and, although there are instances in which the power of reciprocal decomposition is possessed by bodies; yet there are others in which it has not been observed and in which likewise the decomposition appears to be complete, such, e. g. as that tartrate of lime and oxalate of lead may be decomposed entirely by sulphuric acid, just in sufficient quantity to neutralize the lime and oxide of lead in these salts. These facts are stated by Mr. Pfaff.

LV. In some cases, affinities more complicated than those we have hitherto stated, are found to obtain. They are exerted between two primary compounds, both being decomposed and two new compounds being produced. To this kind of action, Bergman gave the name of Double Elective Attraction, and Berthollet, that of Complex Affinity. Thus, sulphate of barytes is composed of sulphuric acid and barytes; but if potash, which has a strong affinity for the acid, be added, no decomposition will take place; if the potash, however, be previously combined with carbonic acid, and this carbonate be boiled with the first compound, both will be decomposed, for the affinity of sulphuric acid and potash will be aided by the attraction of barytes and carbonic acid, and the result of the experiment will be sulphate of potash and carbonate of barytes. If solutions of nitrate of lime and sulphate of pot-

* Researches into the laws of Affinity. Chemical Statics, vol. i.

ash be mixed, sulphate of lime and nitrate of potash will be formed; and, in the same way, sulphate of lead and acetate of zinc may be produced from acetate of lead and sulphate of zinc. In some of these cases, examples may be found of reciprocal decomposition; thus, sulphate of potash will decompose carbonate of barytes; yet, sulphate of barytes may be decomposed by carbonate of potash. The affinities, which preserve the elements of the two compounds in contact, have been called *quiescent*, and those, which tend to separate and combine them in a different manner, *divellent*. Various diagrams have been invented to expose the actions which take place in these decompositions and combinations, and they may be found in most chemical works.

LVI. Bergman, and after him Mr. Kirwan, attempted in these diagrams to show the real forces which cause the double decompositions, by attaching numbers to the acids and bases; but, notwithstanding the utmost care was taken in the estimation of the different affinities, the numbers of the last were incorrect, and the mode of ascertaining this fact was pointed out by M. Guyton, who, probably, derived his data from the general facts discovered by Richter. It consists in mingling two neutral salts which mutually decompose each other, and ascertaining whether the neutral state is preserved, or whether there be an excess of acid or base. By taking them in the quantities, which, according to Kirwan's tables, are required for neutralization, the effect will show how far his numbers are correct, and whether calculation agrees with experiment. On making the trial, it was found that when sulphate of soda was added to muriate of barytes, the soda was not sufficient to neutralize the muriatic acid; and that when a certain quantity of sulphate of potash in solution was mixed with solution of nitrate of lime, the fluid did not exhibit the least trace of nitric acid, although according to calculation from the tables, there should have been 64.87 parts of acid uncombined.*

LVII. The phænomena, which take place in double affinity, occupied the attention of Richter for several years, and from the

* Nicholson's Journal, 4to. vol. ii. p. 340.

results of his experiments, he drew the important conclusions, that all neutral salts, which remain neutral, when their solutions are mixed, are so composed, that the quantities of the different bases that saturate one of the acids present in the mixture, follow the same proportions in saturating the other acids ; and that a metallic neutral salt, the metal of which is precipitated by another metal, changes its metal only ; while the portion of oxygen that enters into the metallic oxide, and the acid with which it is saturated, continue the same ; and that the different metallic oxides which saturate a given portion of any acid, all contain the same quantity of oxygen. Accordingly, he constructed tables which were intended to exhibit the weight of each base capable of saturating 100 parts of the respective acids ; and the weight of each acid requisite to saturate 100 parts of the different bases. Hence, it is easy to account for the state of neutrality, which exists after double decompositions have taken place ; for suppose a solution of sulphate of zinc to be added to acetate of lead, the oxide of zinc is just sufficient to saturate the acetic acid, and the sulphuric acid just sufficient to neutralize the oxide of lead. The decomposition, therefore, takes place in those proportions which are required to preserve the neutral state of the new compounds.

LVIII. The facts, discovered by Richter and others, led to researches which appear to have terminated in the development of the general truth, that when bodies unite chemically, and intimately with each other, the elements always exist in the compounds in certain ratios to each other. Thus, sulphate of barytes is composed of 34 parts of acid and 66 parts of base, and the proportion is always the same ; for if 100 of sulphuric acid be added to 100 of barytes, these bodies, instead of combining so as to form 200 of sulphate, will produce only about 151 parts of the neutral compound, and 49 parts of the acid will remain in a free state. Carbonate of lime, in its various forms, is found to be composed, in round numbers, of 44 of carbonic acid and 56 of lime ; and 2 measures of

hydrogen gas mixed with 1 measure of oxygen gas and inflamed, are totally condensed into water; nor is there any known compound of these elements containing different proportions.

LIX. Some bodies are capable of combining with each other in more than one proportion, yet, in these cases also the proportions are well defined, nor are the subjects capable of uniting in intermediate degrees. Proust discovered that the proportion of oxygen in different metallic oxides, and in the different oxides of the same metal are constant and determinate. Mercury combines with two, lead with three, and antimony, according to Berzelius, with four proportions of oxygen, and although there is a considerable space between the numbers representing these proportions, yet the combinations are never intermediate.

LX. It appears, then, that bodies unite with each other in certain determinate quantities; and the important law has been developed by Mr. Dalton, Dr. Wollaston and M. Gay Lussac, *that when one substance is combined with another in more than one proportion, it exceeds by a ratio to be expressed by some simple multiple of the first.* Thus, the neutral or bi-carbonate of potash contains just twice as much carbonic acid as the sub-carbonate. The oxygen in the peroxide of mercury is to the oxygen in the protoxide, as 2 : 1. There are two sulphurets of tin, and the one contains twice as much sulphur as the other. M. Gay Lussac has demonstrated, that when gaseous bodies unite with each other, it is always in the ratio of 1 to 1, 1 to 2, 1 to 3, &c. so that the higher proportions are multiples of the first. Thus, 100 measures of ammonia neutralize 100 of muriatic acid. There are two compounds known of ammonia and fluoboric gas, one composed of equal measures, the other of 2 volumes of the former and 1 of the latter. Carbonic acid and ammonia unite either in equal volumes, or in the ratio of 2 : 1. The compounds of oxygen and azote present the most perfect illustration of this law. They are found to combine in five proportions, and if

the azote be represented by 175, the numbers indicating the amount of the oxygen will be exhibited in the following table.

Protoxide of Azote	- - -	175 Azote	100 Oxygen.
Dentoxide of Azote	- - - -	175 Azote	200 Oxygen.
Nitrous acid gas	- - - -	175 Azote	300 Oxygen.
Nitrous acid	- - - - -	175 Azote	400 Oxygen.
Nitric acid	- - - - -	175 Azote	500 Oxygen.*

M. Gay Lussac discovered that the contractions in volume, during the combinations of some of the elastic fluids, likewise bear simple ratios to the volumes employed.

LXI. If, then, the proportions in which bodies chemically combine are definite, and if these proportions bear simple ratios to each other, there must exist some cause for this permanency of constitution; and the investigations, which have been made for the purpose of ascertaining this cause, have given rise to the *Corpuscular*, or *Atomic Theory*.

LXII. Some of the ancient philosophers, and particularly Epicurus, maintained, that the elements of matter consist of solid, impenetrable and indestructible atoms;† and this hypothesis appears to have been favoured by Newton. “It seems probable to me,” says this philosopher, “that God in the beginning formed matter in solid, massy, hard, impenetrable, and moveable particles, of such sizes and figures, and in such proportions to space, as most conduced to the end for which he formed them; and that these primary particles, being solids, are incomparably harder than any porous bodies compounded of them, even so hard as never to wear, or break in pieces, or be liable to a change in their nature, or texture.”‡

From this view of the constitution of matter, it followed, that when different species united to form a compound, they combined particle with particle, or a determinate number of particles of one body, with two or more particles of another body, and such, it appears, was the idea of this great philosopher.§ Yet, notwithstanding this doctrine was general-

* Thomson's System, vol. iii. fifth ed.

† Enfield, vol. i. p. 495.

‡ Opera, t. iv. p. 260. ed. Horsley.

§ Opera, t. iv. Quæst. 31.

ly, perhaps universally admitted, the consequences, which flow from its adoption, were not perceived until near the commencement of the nineteenth century. The reason may have been, that the art of analysis was not then sufficiently refined to show the agreement between experience and theory. Mr. Higgins, in his *Comparative view of the Phlogistic and Antiphlogistic theories*, published in 1789, seems to have been the first who directed the attention of chemists to this part of the philosophy of the science, and who stated the results of experiments, which were made with the view of determining the number of atoms of the different elements in certain compounds. This work, however, being written upon controversial subjects, was not very familiar with succeeding chemists, and although it possessed great merit, did not appear to have been extensively circulated, and known. It was not until the year 1804, that the Atomic theory received its present form from Mr. Dalton.

LXIII. By this philosopher, it is concluded that the elements of matter consist of atoms, which, in homogeneous bodies, are all of the same size, form, and density; and, that when they enter into chemical combination, they unite atom with atom, or 1 atom of one with 2, 3, or a greater number of atoms of another; and, in order to represent this mode of union, the following table was constructed, in which the combining bodies are represented by A and B.*

1 atom A + 1 atom B = 1 atom C, binary

1 atom A + 2 atoms B = 1 atom D, ternary

2 atoms A + 1 atom B = 1 atom E, ternary

1 atom A + 3 atoms B = 1 atom F, quaternary

3 atoms A + 1 atom B = 1 atom G, quaternary &c.

It appears, however, that this theory was subsequently so far modified by its author as to admit, that in compounds containing more than one proportion of the elements, 2 or more atoms of one might combine with 1, 2, or more atoms of the other.† Thus, for example, nitrous oxide is conceiv-

* New system of Chemical Philosophy, Part 1. p. 215.

† Annals of Philosophy, vol. iii. p. 176.

ed by Mr. Dalton to be composed of 2 atoms of azote + 1 atom of oxygen; sub-nitrous acid of 2 atoms of azote united with 3 of oxygen; and nitric acid of 2 of the former, with 5 of the latter.*

LXIV. If the atomic theory be adopted, it is of much consequence to ascertain the relative weights of the atoms of the different elements; for the number of atoms composing a compound, and their weights being determined, it would be easy to designate the proportions by numbers. This was done by Mr. Dalton; and as it was necessary to have a standard to which the weights of other atoms might be referred, this chemist has made choice of hydrogen for the purpose, the relation in weight between this element and oxygen, being derived from the constitution of water. An atom of this liquid is inferred to be formed of 1 atom each of these elements, and the weights of them which form the compound, being ascertained by experiment, it was found, that if the weight of the atom of hydrogen were considered as unity, that of oxygen would be 7 nearly. The relative weights of the atoms of oxygen and hydrogen being thus known, it was easy to find the weights of the other elements with which they are capable of combining. Hence, Mr. Dalton has exhibited in the following table the relative weights of a considerable number of the elementary bodies, all of which are referred to that of hydrogen as unity.

1 Hydrogen	- - 1	11 Strontites	- - 46
2 Azote	- - 5	12 Barytes	- - 68
3 Carbon	- - 5	13 Iron	- - 38
4 Oxygen	- - 7	14 Zinc	- - 56
5 Phosphorus	- - 9	15 Copper	- - 56
6 Sulphur	- - 13	16 Lead	- - 95
7 Magnesia	- - 20	17 Silver	- - 100
8 Lime	- - 23	18 Platina	- - 100
9 Soda	- - 28	19 Gold	- - 140
10 Potash	- - 42	20 Mercury	- - 167

* Annals of Philosophy, vol. ix. p. 193.

LXV. From these views of combination, Mr. Dalton derives the following general rules, which he thinks may be adopted as guides in all investigations into chemical synthesis.

1. When only one combination of two bodies can be obtained, it must be presumed to be a *binary* one, unless some cause appear to the contrary.

2. When two combinations are observed, they must be presumed to be a *binary* and a *ternary*.

3. When three combinations are obtained, we may expect one to be *binary*, and the other two *ternary*.

4. When four combinations are observed, we should expect one *binary*, two *ternary*, and one *quaternary* &c.

5. A *binary* compound should always be specifically heavier than the mere mixture of its ingredients.

6. A *ternary* compound should be specifically heavier than the mixture of a *binary* and a simple, which would, if combined, constitute it, &c.

7. The above rules and observations equally apply, when two bodies, such as C and D, D and E, &c. are combined.

Mr. Dalton has likewise ingeniously devised symbols to represent the different atoms, and their modes of union.

LXVI. The theory of Mr. Dalton has been supported with some modifications by Dr. Thomson. He has taken oxygen as the standard, representing it by unity, or 1.000; and seems to have adopted the rule, that where there is more than one compound of the same substances, one of the elements always enters as unity. It follows, that the numbers representing the relative weights of the atoms of different elements, must vary essentially from those of Mr. Dalton. The numbers for oxygen and hydrogen were obtained from the composition of water; the specific gravities of the gases being respectively as 1.104 : 0.073, and 2 volumes of the latter being combined with 1 volume of the former in water, the ratio in weight of the elements in that liquid will be as 7.56 : 1. Hence, oxygen being taken as unity, the weight of the atom of hydrogen must be 0.132. But in his more recent calcula-

tions, Dr. Thomson has adopted the idea of Dr. Prout, that atmospheric air is a chemical compound of 2 atoms of nitrogen, and 1 of oxygen,* upon which supposition, the specific gravity of oxygen gas will be 1.1111, and that of hydrogen, from the composition of ammonia, 0.0694; whence it will follow, that the ratio of these elements in water is as 1 of hydrogen to 8 of oxygen; and the atom of the latter being considered 1.000, that of the former will be 0.125. The following table of the weights of atoms, collected from the last edition of his *System of Chemistry*, will show that they differ of course from those of Mr. Dalton, and from those also which he had himself previously calculated.†

1 Oxygen	-	-	1.000	11 Strontites	-	-	6.500
2 Azote	-	-	1.750	12 Barytes	-	-	9.750
3 Carbon	-	-	0.750	13 Iron	-	-	3.500
4 Hydrogen	-	-	0.125	14 Zinc	-	-	4.125
5 Phosphorus	-	-	1.500	15 Copper	-	-	8.000
6 Sulphur	-	-	2.000	16 Lead	-	-	13.000
7 Magnesia	-	-	2.500	17 Silver	-	-	13.750
8 Lime	-	-	3.625	18 Platina	-	-	22.625
9 Soda	-	-	4.000	19 Gold	-	-	24.875
10 Potash	-	-	6.000	20 Mercury	-	-	25.000

LXVII. The facts relating to the combinations of the elastic fluids and the mode of expressing them by volumes, as developed by the researches of M. Gay Lussac, having been found convenient, and hence generally adopted, it became a point of some consequence to those who supported the atomic theory to ascertain what relations existed between the specific gravities of gaseous bodies, and the weights of their atoms. This relation was first pointed out by Dr. Prout, who has shown, that the specific gravity of any body may be obtained by multiplying the weight of its atom by half the specific gravity of oxygen gas; which, observes Dr. Thomson, is the same thing as saying, that the weight of the atom of a body is always double its specific gravity in the form of gas.

* *Annals of Philosophy*, vol. vi. p. 322.

† *Ibid.* vol. ii.

The chemist last mentioned, after investigating this subject, has drawn as a conclusion, that when all the substances which can exist in the gaseous form are examined, they may be reduced to three classes. In the first, the specific gravity of the body, and the weight of its atom, are represented by the same number; in the second, the weight of the atom is double that of the specific gravity; and in the third class, the weight of the atom is quadruple the weight of a volume of the respective bodies.* In these tables, the calculated results are founded upon the supposition, that the specific gravity of oxygen gas is 1.1111, which is the true number, if Dr. Prout's idea of the chemical constitution of the atmosphere be correct. But this opinion does not accord with the analysis of the air, and it would have been safer to have employed the number denoting the specific gravity, as derived from direct experiment. The views of Dr. Prout on this point must be considered as hypothetical.

From these tables it appears, that the relation above mentioned is very simple. The law seems applicable to all simple substances excepting oxygen and the conclusion on inspecting them, says Dr. Thomson, is, that the ultimate atoms of bodies differ in weight, and that the ratios of their weights may be determined by their specific gravities.

LXVIII. In 1814, Dr. Wollaston, a celebrated English philosopher, who has contributed so much to the development of the theory of definite proportions, gave to the practical chemist a valuable instrument in his *Scale of Chemical Equivalents*. The principle, upon which it is constructed, is founded upon the facts discovered by Richter, relating to the mutual decompositions and combinations of bodies, and upon the ratios or equivalent numbers which represent the amount of bodies required for mutual saturation.

Within a very small space, are stated the composition of any of the known salts, the quantity of any other salt required completely to decompose it, the amount of the salt thus

* Annals of Philosophy, vol. vii. pp. 17—343.

formed, the proportion of its elements, the quantity of water it contains, the quantity of any other acid required to neutralize its base; and an immense number of facts of the same kind; so that by mere inspection of the scale, the information which was before scattered through the pages of different works upon chemistry, or which could be acquired only by arithmetical calculation, may be at once obtained.* The standard to which are referred the weights of other substances is oxygen, and it is represented by 10. Of course, it is easy to accommodate it to the numbers of Dr. Thomson. In order to convert the numbers of this scale into those of Mr. Dalton, it is required only to multiply by 7, and divide by 10.

It appears that a scale upon the same principle, but possessing some advantages over that of Dr. Wollaston, has been invented in Italy.† It is his table disposed around a moveable circle, within which is another considerably augmented and modified. The numbers are carried to 1000, which correspond with the 10 of the chemical equivalents. The improvements consist, 1. in indicating quantities lower than 10 and higher than 1000. 2. In avoiding arithmetical calculations, which are required in Wollaston's table for quantities not marked upon it, when the proportions of the constituents of a compound are to be found. 3. In accommodating the numbers representing quantities, to those of Dalton's, Davy's, or Berzelius's system. From these circumstances, it is probable that this modification of the scale of equivalents will soon come into common use.

LXIX. Notwithstanding the simplicity of the atomic theory, and its apparent adaptation to the general facts, which have been established relative to the proportions in which bodies combine, it will be found, when examined in detail, to present some serious difficulties, and that to render it complete, certain positions must be assumed, which are

* Plate 1. and *Explanation*.

† Journal of the Royal Institution, vol. iii. 397.

not countenanced by actual knowledge of facts. It is said that it does not follow, because bodies unite in definite proportions, which bear simple ratios to each other, that the first combination is that of atom to atom, and the other proportions are those of one atom to two, three, or four. It is possible, that instead of attraction being exerted from atom to atom individually, a certain number of atoms of a body may exert the most powerful force, and enter into the combinations it forms; and all that is strictly established is, that whatever number enter into the first compound, double that number enter into the second combination, and three or four times the number into the third and fourth.* The doctrine, then, is obviously hypothetical, and the assumption, which, however, is not always strictly adhered to, that in several combinations of the same elements, one of them enters as unity, is merely to facilitate the calculation of the relative weights of the respective atoms. Several facts, indeed, were found to be opposed to this conclusion. Thus, iron forms two compounds with oxygen; in the first the ratio by weight is 100 of metal + 30 of oxygen; in the second, 100 + 45. Now, if the first compound be considered as composed of 1 atom each of the elements; the second must consist of 1 of iron, united with $1\frac{1}{2}$ of oxygen. But an atom is supposed to be indivisible, and theory in this instance does not accord with fact. Sulphur offers the same difficulty, for 100 parts by weight of this substance combine with 100 of oxygen to form sulphurous acid; and with 150 to constitute sulphuric acid. Here the ratio of oxygen to the base is the same as in the case of the oxides of iron, viz. 1 to $1\frac{1}{2}$. To obviate the force of this objection, Mr. Dalton proposed to double the preceding numbers, and to consider the ratio as 2 to 3. This removes the difficulty with regard to the half atom, but it obliges us to suppose, that there exists a compound of 1 atom each of iron and oxygen, and another of 1 atom each of oxygen and sulphur, which have not yet been

* Murray's Elements of Chemistry, vol. i. 65. 4th edit.

discovered. Dr. Thomson now considers the protoxide or first compound of iron and oxygen to consist of 1 atom of each, and the second or peroxide of 2 of iron united with 3 of oxygen, and he is drawn into the singular conclusion, that the equivalent number for the peroxide is less than that for the protoxide.* With respect to sulphur, the first compound or sulphurous acid contains 1 atom of sulphur + 2 atoms of oxygen, and sulphuric acid consists of 1 atom of sulphur + 3 of oxygen. The third compound composed of 1 atom of each is supposed to be contained, in the form likewise of an acid, in the *sulphuretted sulphites*. But this acid has never been obtained in a separate state; nor does Dr. Thomson give the facts upon which his proof of its existence is founded.†

LXX. The view taken by Sir Humphry Davy of this subject is much more simple. After having, by a series of facts, extensively and elegantly illustrated the general principles, that bodies combine in definite proportions, and that where more than one compound of the same bodies is known, the second or third proportion is a multiple of the first, he proceeds to observe, that “in the doctrine of proportions derived from facts, it is not necessary to consider the combining bodies either as composed of indivisible particles, or even as always united one and one, one and two, or one and three proportions;—and at present, as we have no means of judging either of the relative numbers, figures, or weights of those particles which are not in contact, our numerical expressions ought to relate solely to the results of experiments.”‡

“As in all well known compounds, the proportions of the elements are in certain definite ratios to each other, it is evident that these ratios may be expressed by numbers; and, if one number be employed to denote the smallest quantity in which a body combines, all other quantities of the same body will be multiples of this number; and the smallest proportions

* System of Chemistry, vol. i. p. 370. 5th ed.

† Ibid, vol. ii. p. 112.

‡ Elements, part i. p. 115. Eng. ed.

in which the undecomposed bodies being known, the constitution of the compounds they form, may be learnt; and the element which unites chemically in the smallest quantity being taken as unity, all the other elements may be represented by the relations of their quantities to unity."* For this purpose, hydrogen has been chosen, because it enters into combination in smaller proportions by weight, and has more of the characters of an element than any other body. It appears to exist in no definite compound in less proportion than in water, and from the composition of this liquid, therefore, in common with Mr. Dalton, Sir Humphry derives the numbers which express the relative proportions of hydrogen and oxygen. "The specific gravity of hydrogen to oxygen is as 1 to 15; and as 2 volumes of hydrogen to 1 of oxygen enter into the composition of water, the ratio of hydrogen in water will be to the oxygen as 2 to 15; and it may be regarded as composed of 2 proportions of hydrogen and 1 of oxygen; and the number representing hydrogen will be 1, and that representing oxygen 15." From this mode of calculating the numbers, Sir Humphry has doubled the one intended to represent the oxygen, and it was done for the purpose of making it an integer, but the slight advantage resulting from this method is more than counterbalanced by the inconvenience arising from his having, in fact, adopted two standards. The numbers for hydrogen and oxygen having been obtained, it was easy to calculate those of other elementary substances.

The following table, collected from the Elements of this distinguished chemist, exhibits the proportional numbers representing some of the simple bodies.

1 Hydrogen	-	-	1	9 Sodium	-	-	88
2 Oxygen	-	-	15	10 Barium	-	-	130
3 Azote	-	-	26	11 Manganese	-	-	113
4 Chlorine	-	-	67	12 Iron	-	-	106
5 Sulphur	-	-	80	13 Lead	-	-	398
6 Phosphorus	-	-	20	14 Copper	-	-	120
7 Carbon	-	-	11.4	15 Silver	-	-	205
8 Potassium	-	-	75	16 Arsenic	-	-	90

* Elements, Part i. p. 112.

LXXI. The difficulties, which are presented in the Atomic theory, induced professor Berzelius to propose a modification of this doctrine. It is founded upon the laws of definite proportions, and upon the discoveries of M. Gay Lussac relating to the combinations of the elastic fluids; it is called the Theory of Volumes. The principles of the French chemist he applies to solids and liquids, as well as to gases, for, says he, "from what we know respecting definite proportions, it follows, that it would hold with all bodies at the temperature and pressure at which they would assume the gaseous form. Hence, there is no other difference between the theory of volumes and that of atoms, than that the one represents bodies in the gaseous, the other in a solid form. It is clear, that what in one theory is called an *atom*, is in the other theory a *volume*. In the present state of our knowledge, the theory of volumes has the advantage of being founded upon a well constituted fact, while the other has only a supposition for its foundation. In the theory of volumes, we can figure to ourselves a *demi-volume*, while in the theory of atoms a *demi-atom* is an absurdity." But, "here as well as in the atomic theory it is absolutely necessary, that in each compound, one of the constituents should enter as unity."* It was equally requisite to determine upon, and adopt some general measure or standard, to which the weights of the volumes of other elementary substances might be referred, and for this purpose, Berzelius has made choice of oxygen, a volume of this elastic fluid being represented by 100.

LXXII. From what has been said in the preceding paragraphs respecting chemical synthesis, it will appear that the most distinguished chemists in Europe are agreed in considering as laws of this science, 1. *that bodies combine with each other in definite proportions*, and 2. *that in cases in which there exists more than one proportion, it exceeds by a ratio that may be expressed by a simple multiple of the lowest proportion*. It is, however, much to be regretted, that they have differed not

* On Chemical Proportions. Annals of Philosophy, vol. ii. p. 250.

only in the views which they have taken of the cause of this constancy of combination, but also in the element, the weight of which is selected as the standard. Great confusion has necessarily resulted from this discordance of opinion, and the numbers of Dalton, Davy, Thomson, and Berzelius, can be made to agree only by arithmetical calculation. By the two former, hydrogen is taken as the unit, and the relative weight of oxygen is deduced from the composition of water. Mr. Dalton, considering this liquid as a compound of 1 atom each of the two elements, has stated the ratio of their weights as 1 : 7 nearly. Sir H. Davy, on the other hand, regarding water as composed of 2 proportions of hydrogen, and 1 proportion of oxygen, has, in making hydrogen the unit, doubled the number for oxygen, the ratio being determined as 1 : 15, and has thus introduced some confusion into his statements of the relative weights of the other elements. Thus, when referred to hydrogen, chlorine is represented by 33.5 ; but it is 67 when compared with that of oxygen ; and in the number for sulphur, that body is sometimes indicated by 15, and at others by 30 ; in the first case being referred to hydrogen and in the second to oxygen. These numbers must of course have a corresponding influence upon those by which others are represented.

By Drs. Thomson and Wollaston, and Professor Berzelius, oxygen has been taken as the unit.

LXXIII. The theory of volumes of M. Gay Lussac applies extremely well to the elastic fluids, particularly since the discovery of the relations of their specific gravities to the weights of their atoms. But Berzelius, who has modified this theory, has erred in saying that, what in one theory is called an atom, is in the other considered as a volume ; for, there are several compounds, and among them we may mention water, which, in reference to the former, are composed of an atom each of two elements ; while, in the latter, they are considered as consisting of two volumes of one body united with one

volume of another body. We cannot, in fact, conceive of a volume upon the principles of this theory ; for a volume of an elastic fluid is composed of atoms or particles which are mutually repulsive ; but an atom is considered as indivisible, and there is, therefore, no power with which we are acquainted capable of giving it a gaseous form, although this state may be communicated to two or more particles.

LXXIV. Such are the views which have been taken by different chemists, of the doctrines of multiple proportions ; and the question now arises, which of them is it expedient to adopt ? The atomic theory is alluring. The principles which it offers, coincide with our experience of the properties of matter, and agree with the opinions of the greater part of philosophers, respecting its constitution. But the foundation itself is hypothetical, many facts offer difficulties which are but imperfectly obviated, the uncertainty which still exists respecting the composition of a variety of compounds, permits only a limited application of its principles, the different modes which have been proposed by Mr. Dalton and Dr. Thomson render a choice perplexing, and time and much research are necessary to put it in a form in which it can be considered as one of the fundamental theories of chemistry. On the contrary, if the amount of combining bodies be expressed in proportions, it is simply an enunciation of facts, and is totally independent of all hypothetical opinions respecting the ultimate forms or constitution of matter. This mode appears to me most philosophical, and it has therefore been adopted, but it is due to those who have proposed the atomic theory to state their views of the composition of bodies, and, hence, wherever it is practicable, such compositions will be designated in proportions, in weights and in atoms.

LXXV. The next question to be decided is, what element shall be taken as the unit ? The choice lies between hydrogen and oxygen. In favour of the former, it is said that hydrogen is the body which enters into combination in the smallest proportion by weight ; that of all other substances it has

the greatest claim to the name of element ; that from its low specific gravity it is not probable it will ever be proved to be compound, and that it will thus always constitute a permanent and undeviating standard. On the other hand, it has been remarked that from the rarity of hydrogen, it is extremely difficult to obtain its true specific gravity ; that if its weight be taken as unity, the numbers representing the weights of many of the other elements must be inconveniently large ; that oxygen enters into the composition of a greater number of compounds, which are more important in themselves and more familiar to chemists, than those of hydrogen ; and that the difference in the relative weights of the other elementary bodies will be much less, and their expression more convenient when referred to oxygen. The arguments, undoubtedly, preponderate on the side of hydrogen, and these have determined me to adopt that element as the standard of reference, and to express its weight by unity.

LXXVI. It remains only to state the mode by which the numbers representing the other elements may be gained. The relative weights of hydrogen and oxygen being known, it will be easy to obtain those of other substances. These, then, may be deduced from the composition of water. The ratio of the hydrogen to the oxygen in water may be determined by the specific gravities of the gases. Two volumes of the former united with one volume of the latter, constitute this liquid, and the specific gravity of hydrogen is to that of oxygen, as 0.0732* to 1.1088 ;† now $0.0732 : 1.1088 :: 1 : 15$ nearly ; but, as 2 measures of hydrogen enter into the composition of water, the ratio is as 1 to 7.5. and these numbers express the proportions of the elements by weight in this liquid. Dr. Prout has stated the specific gravities of these gases differently, and in employing them, the decided advantage would be gained, of expressing the number for oxygen by an integer, the ratio according to him being as $1 : 8$.‡ But the specific

* Biot and Arago. † Allen and Pepys.

‡ Annals of Philosophy, vol. vi. p. 321.

gravity of hydrogen is derived by calculation from the composition of ammonia, and it is at least doubtful, whether this mode have any advantage over that in which the weight of the gas is obtained by direct experiment. Water, then, is composed of 1 proportion of oxygen 7.5, and 1 of hydrogen 1; and its representative number is 8.5.

The number for nitrogen may be obtained from the composition of nitrous oxide. This gas has been shown by M. Gay Lussac to be composed of two volumes of nitrogen combined with one volume of oxygen. The specific gravity of nitrogen is 0.9691; and $0.0732 : 0.9691 :: 1 : 13$ nearly. Now, 7.5 representing a volume of oxygen, we may conclude, that nitrous oxide is composed of 1 proportion of nitrogen, 13 and 1 of oxygen 7.5, and it will be represented by 20.5; the number for nitric oxide, which contains 2 proportions of oxygen, will be $13 + 15$, or 28; that of nitrous acid gas $13 + 30 = 43$; and of nitric acid $13 + 37.5$, or 50.5. According to Sir H. Davy, oxide of zinc contains about 18 per cent. of oxygen, and as there is but one well known compound of these substances, it may be considered as composed of 1 proportion of each; and $18 : 82 :: 7.5 : 34$ nearly. The fourth term of the proportional, therefore, gives us the representative number for the metal, and $34 + 7.5 = 41.5$ for the oxide.

One other example will, we presume, be sufficient to illustrate the general method by which the numbers of the elements and of their compounds may be found. Chloric acid is a compound of chlorine and oxygen; and the specific gravity of chlorine is to that of hydrogen, as 33.5 to 1. The number, therefore, for the first, is 33.5. M. Gay Lussac has shown, in his memoir on Iodine, that the proportions of the substances in chloric acid may be ascertained by the decomposition of the salt called chlorate of potash, of which it constitutes one of the ingredients; 100 parts of it when exposed to heat yield 38.88 of oxygen, and 61.12 of chloride of potassium, which chloride consists of 28.924 of chlorine and 32.196 of metal. But 32.196 of potassium require 6.576 of oxygen

to be converted into the potash which had been previously united with the chloric acid. Part of the oxygen, then, obtained by the decomposition of the salt, must have been derived from the potash, for the chloride which remains consists of the base only of the potash, combined with chlorine; this oxygen amounts to 6.576 parts, which, when subtracted from 38.88, leaves 32.304 for the oxygen contained in the chloric acid. Now potash is a protoxide of potassium, or a compound of 1 proportion each of oxygen and potassium; 6.576 here represent the proportion of oxygen, and this number multiplied by 5 gives 32.880. Chloric acid, then, is composed of 1 proportion of chlorine 33.5, and 5 proportions of oxygen 37.5, and will be represented by 71. If we wish to ascertain the proportions of the elements by weight in 100 parts of the acid, we shall find that $28.924 : 32.304 :: 47.24 : 52.76$; and that it is composed of 47.24 of chlorine, and 52.76 of oxygen.



CHAPTER II.

OF HEAT, OR CALORIC.

LXXVII. The term Caloric is appropriated to the cause which produces in us the sensation of heat. Philosophers are not yet agreed respecting the nature of this cause. By many, it is considered as material and as existing in the form of an attenuated subtile fluid, the particles of which powerfully repel each other, while they exert a strong attraction for those of other matter. Others, on the contrary, conceive that the phenomena of heat depend upon the motions of the particles of bodies; that caloric has no independent existence, and is to be considered merely as a property of matter which requires certain conditions for its development. The language employed in describing its effects, almost necessarily leads to hypothetical views respecting its modes of existence, and when we read of its absorption and disengagement, of its flowing into, or out of bodies, of latent heat, of the capacities of bodies to contain caloric, and of its projection or radiation from heated surfaces, the conclusion must follow, that caloric is matter. Without entering, here, into a discussion of the comparative merits of these hypotheses, we shall proceed to describe its effects, premising that the operation of caloric is repellent, and, as such, is opposed to the influence of Attraction.

SECTION I.

Expansion.

LXXVIII. Expansion is the most general and familiar of all the effects of Caloric. It takes place in all forms of matter. If a metallic rod be fitted to a guage so as when cold to pass under two projecting arms, and through a perforation of equal diameter, it will be found that when heated strongly, its bulk is so much enlarged as to prevent it from passing under the arms, or through the ring. If a tube with a narrow bore, and having a bulb at one end, be partly filled with a coloured

liquid, and be then exposed to a source of heat, the liquid will rise, or occupy a greater space than before; and a bladder, partly filled with air, when placed before a fire, will gradually become distended, and may even be burst by the expansive power of the included air. On the contrary, if the flaccid bladder, the tube containing the liquid, and the metallic rod be exposed to cold, or, in other words, if the caloric be reduced, and they be measured, their bulks will be found to be diminished. All classes of bodies, then, are expanded by an increase, and diminished in volume by a reduction of heat.

LXXIX. The amount of expansion in bodies from a given increase of caloric, is dependent both upon their forms and their natures. When the forms alone are considered, it takes place inversely as the density. Liquids expand more than solids, and elastic fluids more than liquids. Supposing the augmentation of heat equal to 180° , the expansion of steel will amount to 0.0011899, or $\frac{1}{84.6}$; of water to 0.0466, or $\frac{1}{21.5}$; and of air to 0.37500, or $\frac{1}{2.7}$. But this law does not obtain among bodies of the same class. Thus, with regard to the metals, the tables of Mr. Smeaton, of Mr. Troughton, and of M. M. Gay Lussac and Arago, have shown, that a great diversity exists, and that their rates of expansion can be referred to no general law, unless, perhaps, it be their fusibilities. As the knowledge of the dilatations of solids is of considerable practical importance, their rates of augmentation, by a given increase of heat, will be stated in the following tables. In Mr. Smeaton's, the increase of heat is equal to 180° , and the expansion of a white glass barometer tube is taken as the standard, being expressed by 000.100. The metals expand in the following order.

	In Decimals.	Vulgar Fractions.
Antimony - - -	000.130	$\frac{1}{769}$
Blistered Steel - - -	000.138	$\frac{1}{724}$
Hard Steel - - -	000.147	$\frac{1}{680}$
Iron - - -	000.151	$\frac{1}{662}$
Bismuth - - -	000.167	$\frac{1}{598}$
Hammered Copper - - -	000.204	$\frac{1}{490}$
Brass, cast - - -	000.225	$\frac{1}{444}$
Fine Pewter - - -	000.274	$\frac{1}{364}$
Grain Tin - - -	000.298	$\frac{1}{33}$
Lead - - -	000.344	$\frac{1}{290}$
Zinc, hammered - - -	000.373	$\frac{1}{268}$

The following are from the tables of M. M. Gay Lussac and Arago, as calculated from the experiments of M. M. Lavoisier and La Place.* Increase of heat = 180° Fah. the volume at 32° being 1.00000000.

Tube of Crown Glass	1.00087572	-	-	$\frac{1}{1142}$
Tube of Flint Glass -	1.00081166	-	-	$\frac{1}{1248}$
Copper - - -	1.00172244	-	-	$\frac{1}{581}$
Iron, forged - - -	1.00122045	-	-	$\frac{1}{819}$
Steel, untempered	1.00107875	-	-	$\frac{1}{927}$
Lead - - -	1.00284836	-	-	$\frac{1}{351}$
Tin, Malacca - - -	1.00193765	-	-	$\frac{1}{518}$
Tin, English - - -	1.00217298	-	-	$\frac{1}{462}$
Silver, pure - - -	1.00190974	-	-	$\frac{1}{523}$
Gold, pure - - -	1.00146606	-	-	$\frac{1}{682}$
Platinum (Borda) - -	1.00085655	-	-	$\frac{1}{1167}$

Table of Linear dilatations from 32° to 212°, by Mr. Troughton.

Steel - - -	0.0011899	-	-	$\frac{1}{840}$
Silver - - -	0.0020826	-	-	$\frac{1}{480}$
Copper - - -	0.0019188	-	-	$\frac{1}{521}$
Iron wire - - -	0.0014401	-	-	$\frac{1}{694}$
Platinum - - -	0.0009918	-	-	$\frac{1}{1008}$
Palladium (Wollaston)	0.0010000	-	-	$\frac{1}{1000}†$

* Biot, *Traité de Physique*, t. i. p. 158.

† *Annals of Philosophy*, vol. ix. p. 18.

LXXX. The same difference is perceptible in the expansive powers of liquids, as may be proved from the following table of Mr. Dalton, the increase of heat in each being equal to 180° , or to the difference between the freezing and boiling of water.*

Mercury	-	-	0.0200	-	-	-	$\frac{1}{30}$
Water	-	-	0.0466	-	-	-	$\frac{1}{22.5}$
Water, sat'd with salt			0.0500	-	-	-	$\frac{1}{20}$
Sulphuric acid	-		0.0600	-	-	-	$\frac{1}{17}$
Muriatic acid	-		0.0600	-	-	-	$\frac{1}{17}$
Oil of Turpentine			0.0700	-	-	-	$\frac{1}{14}$
Ether	-	-	0.0700	-	-	-	$\frac{1}{14}$
Fixed Oils	-	-	0.0800	-	-	-	$\frac{1}{12.5}$
Alcohol	-	-	0.0110	-	-	-	$\frac{1}{9}$
Nitric acid	-	-	0.0110	-	-	-	$\frac{1}{9}$

LXXXI. It might be supposed, that as the airs or elastic fluids differ from each other in their physical and chemical properties, the same difference should be observed in their relations to caloric, as is found to exist in liquids. But this is not the case, and it has been proved by the experiments of M. Gay Lussac and of Mr. Dalton, that 100 parts of any elastic fluid on being heated 180° , or from 32° to 212° of the thermometer, are expanded to 137.5 parts.

LXXXII. The thermometer, to the invention of which is owing all the knowledge that has been acquired of the relations of caloric, is formed upon the principle, that variations in temperature produce corresponding variations in the volumes of fluids; and that the relative temperature of other bodies may be ascertained by the augmentation, or contraction in volume which is experienced in the thermometric fluid. The thermometer was invented about the commencement of the 17th century, and the merit of having presented this valuable gift to philosophy, is ascribed to Sanctorio or Sanctorius, the celebrated author of statical medicine, who

* New System, Part i. p. 44.

died at Venice in 1636. His apparatus was perfectly simple, consisting of a glass tube of a convenient length, open at one end, and having a bulb attached to the other. The open end was immersed in a coloured liquid, and part of the air in the stem was forced out by the application of heat to the bulb. As it cooled, the liquid rose proportionably into the bore of the tube. An arbitrary scale was attached to it, and when the air was expanded by heat, the liquid fell, but again rose, when it was contracted. Hence, it was a real thermometer, capable of showing variations of temperature in the bodies to which it was applied, by corresponding changes in the volume of the air within the bulb. But from its form, it was inconvenient, from its being exposed to the pressure of the atmosphere, imperfect, and from the nature of the thermometric fluid, incapable of measuring extensive ranges of temperature.*

These imperfections have, in a great measure, been obviated by the ingenuity of Mr. Leslie, who has given to his modification, the name of the *Differential* thermometer. It consists of two air thermometers, one of them containing sulphuric acid tinged with carmine; they are joined together, and bent in the form of the letter U. The bulbs, which are from $\frac{4}{10}$ to $\frac{7}{10}$ of an inch in diameter, being at the distance from each other, of from 2 to 4 inches, and the legs from 4 to 6 inches in length. It is supported upon a convenient wooden frame, and a scale is attached to it, graduated in such a manner, as that each degree shall be equal to $\frac{1}{18}$ of a degree of the scale of Fahrenheit. It is obvious, from its construction, that it is calculated to show only the *difference* of temperature between the two bulbs. If both be exposed to bodies of the same temperature, the expansion of the air in one bulb will be counteracted by an equal expansion of the air in the other, and the coloured liquid will remain stationary; but, if the heat of one be either increased, or diminished, while that of the other continues the same, there will be an expansion or contraction in the air of the former, and the coloured liquid

* Plate iii. fig. 3.

will rise, or fall in the stem of the latter. This instrument may be used with advantage in experiments relating to the radiation of caloric.*

LXXXIII. The first essential improvement in the thermometer was made by the Academicians Del Cimento of Florence, by substituting a liquid, instead of air, as the measurer of variations of heat. They used coloured spirit of wine, which was introduced into a tube having a bulb at one end, and the variations in volume were marked by an arbitrary scale. This kind of instrument was extensively circulated under the name of the Florence glass. But although it was superior to the original thermometer of Sanctorius, yet it was very imperfect, because the liquid was exposed to the air, and the scale was formed without any fixed and certain method. Fahrenheit of Amsterdam first gave it precision, by hermetically sealing the open end, while the liquid, by exposure to heat, was made to occupy the whole of the tube, so that when it again contracted, no air was introduced to disturb the regularity of its operations; and it was perfected by the discovery that the melting point of snow or ice, and the boiling point of water, under the medium pressure of the air, might be employed as undeviating standards in graduating the scale of the instrument. The first of these facts was applied to this purpose by Sir Isaac Newton, and the last by Dr. Hooke. About this time, mercury was substituted for spirit of wine, and for all the general purposes for which the thermometer is employed, it will be found to constitute the most convenient liquid. The space between its freezing and boiling points is so large, that it admits of an extensive range of temperature, and it is proportionably less liable to inaccuracies in its indications. The modern thermometers are constructed as follows: a tube, the bore of which is perfectly uniform, has a bulb of a proper size blown at one end, the other is immersed in dry and pure quicksilver, and a great part of the air contained in the bulb is forced out by exposure to heat. As

* Plate iii. fig. 4.

it cools, the mercury rushes in and occupies the place of the air. The metallic fluid is then boiled, and the vapour formed presses out the remaining air, so that when the mouth of the tube is again immersed, the mercury rises and fills the bore and a part of the stem. The open end is then drawn out to a capillary tube, heat is applied to the bulb, the mercury is made to boil, to render it perfectly dry, and while expanded so as to occupy the whole of the bore, the flame of a lamp is directed by a blow pipe upon the end, it melts and obliterates the tube; hence, as the mercury contracts, the space above is to be considered as a vacuum. When the instrument is plunged into melting snow, the mercury descends to a certain point and there becomes stationary; this point is marked upon the external part of the tube; it is afterwards immersed in boiling water, the quicksilver rises to, and remains fixed at a certain height, which is also marked, and thus, having two determinate and distant points for the graduation, the scale may be divided into any number of equal degrees, for these numbers may easily be made to correspond, by simple arithmetical calculation.

LXXXIV. The mercurial thermometer is said by Boerhaave to have been first used by Olaus Rømer; it was afterwards improved by Fahrenheit. His first thermometers were graduated from three fundamental points, viz. the temperatures of mixed salt and snow, of melting ice, and of the human body. He divided his scale into only 24° , but, probably finding this number too small, the spaces were subdivided by 4, and the whole number amounted to 96° . It has been thought, that the present scale was formed by him upon the principle, that the divisions really express the fractional parts of the dilatation of the whole mass. Thus, the volume of mercury, at zero or 0, being considered as containing 11,124 parts, it would, when put into melting snow, expand $\frac{3}{11,124}$; and when immersed in boiling water, $\frac{21}{11,124}$ parts. It is doubtful, however, whether Fahrenheit followed this plan, and even if he did, it would appear that the credit of applying this phi-

losophical method must be shared with Newton and Boerhaave.*

The present thermometers, which bear the name of Fahrenheit, are graduated from the freezing and boiling points of water, the space between them being divided into 180 degrees. The zero was placed by him at the temperature of a mixture of sal ammoniac and snow, which he supposed to be the greatest degree of cold ever observed. Now, supposing the divisions to be protracted downward from the freezing of water to the temperature of this mixture, the space between them will contain 32 divisions. The freezing point of water is thus placed at 32°, and the boiling point at 212°. To degrees below 0 is sometimes prefixed the mark —, or the word *minus*; and to those above zero, the sign + or *plus*.

LXXXV. Fahrenheit's thermometer is employed only in Great Britain and the United States. On the continent of Europe, the one most commonly used is that which goes by the name of Reaumur. In this instrument, the temperature of melting ice or freezing water is considered as zero, and 80 equal divisions mark the space between this point and that of boiling water. Hence, a degree on Fahrenheit's is equal to $\frac{4}{9}$ of a degree of the scale of Reaumur; and if the number of degrees on Fahrenheit's scale, above or below the freezing of water, be multiplied by 4 and divided by 9, the quotient will give the corresponding number upon the scale of Reaumur. Thus, if it be required to convert 68° of Fahrenheit into those of Reaumur, it may be represented as follows.

$$\begin{array}{rcll} \text{Fah.} & & & \text{Reaum.} \\ 68^{\circ} - 32^{\circ} = 36 \times 4 = 144 \div 9 = 16^{\circ} \\ 212^{\circ} - 32^{\circ} = 180 \times 4 = 720 \div 9 = 80^{\circ} \end{array}$$

To reduce the degrees of Reaumur to those of Fahrenheit, multiply by 9 and divide by 4, and add 32°.

$$\begin{array}{rcll} \text{Reaum.} & & & \text{Fah.} \\ 16^{\circ} \times 9 = 144 \div 4 = 36^{\circ} + 32^{\circ} = 68^{\circ} \\ 80^{\circ} \times 9 = 720 \div 4 = 180 + 32 = 212^{\circ} \end{array}$$

* *Annals of Philosophy*, vols. vi. p. 232, and viii. p. 26.

In France and in the north of Europe, Celsius's or the Centigrade thermometer is often used. The space between the freezing and boiling points of water is divided into 100 degrees, the zero corresponding with the 32° of Fah. A degree of Fah. is equal to $\frac{5}{9}$ of a degree on the scale of this thermometer, hence,

$$\overset{\text{Fah.}}{212^{\circ}} - 32^{\circ} = 180^{\circ} \times 5 = 900 \div 9 = \overset{\text{Cent.}}{100^{\circ}}$$

$$\overset{\text{Cent.}}{20^{\circ}} \times 9 = 180 \div 5 = 36 + 32^{\circ} = \overset{\text{Fah.}}{68^{\circ}}$$

In Russia, the descending scale of De Lisle is sometimes employed, in which the boiling point of water is considered as 0, and the freezing point as 150° . In all the thermometers just noticed, the spaces between the divisions are so large, that in delicate experiments, they often require to be expressed in fractional parts. To obviate this inconvenience, it has been proposed to divide the space between the freezing and boiling of mercury, which now occupies 670° into 1000.

LXXXVI. The Register thermometer is an instrument employed in meteorological observations for the purpose of recording the changes in temperature which have taken place during the absence of the observer. There are two kinds, the first pointing out only the maximum and minimum change; the second exhibiting all the variations which have happened within a given time. The construction of the last is necessarily so complicated, that it has never been introduced into general use. The most common instrument consists of one spirit, and one mercurial thermometer, placed horizontally in grooves in a frame of hard wood, the scales being marked upon the surface of the frame. The bulbs are protected by cases of brass. The spirit thermometer contains a small piece of glass, and the mercurial a fragment of polished steel wire. When the temperature falls, the glass in the first is carried down with the spirit, but when the alcohol again rises, it passes around without moving the foreign body; consequently, the *minimum* temperature may be found by inspecting the

scale opposite to the upper surface of the glass bulb. On the other hand, when the mercury rises, it pushes before it the steel wire, but, when it descends, the wire is left at the point to which it had previously risen; hence, the *maximum* of heat may be readily discovered. They are regulated by being held for a short time in a perpendicular position.

LXXXVII. As the mercurial thermometer is incapable of indicating temperatures much above 600° , attempts have been made to supply the deficiency by instruments which, from their uses, have been called *Pyrometers*. The best known of these are the pyrometers of M. Guyton and of Mr. Wedgewood. The first is founded upon the expansibility of the metal called platinum. A rod of this metal is fitted to a horizontal groove made in a mass of white clay, which has been previously baked; one end being supported by the clay itself, while the other presses against a bended lever of platinum, the longest arm of which forms an index to a graduated arc. When this instrument is heated, the platinum rod expands, the motion is communicated to the lever, and to the arm which passes over a space on the scale proportional to the temperature.

Pure clay, on exposure to heat, suffers a regular contraction in volume until it becomes vitrified. On this fact, Mr. Wedgewood founded the construction of his pyrometer, and executed with it a great variety of experiments. But the dependence which might be placed upon this instrument is much weakened, if not destroyed, by the fact discovered by Sir James Hall, that the pyrometrical pieces of clay contract as much by long exposure to a red heat, as for a short time to a white heat. It is not probable, therefore, that this pyrometer will again come into use.

LXXXVIII. The thermometer, as commonly constructed with equal divisions, is not to be considered as perfectly correct in its indications of temperature. Liquids not only differ in their expansibilities, but the expansion of the same liquid is not uniform for the increase of heat. It has been suf-

ficiently demonstrated, that equal increments of heat produce unequal increments of expansion ; and according to the experiments of Mr. De Luc, the expansion of mercury from 122° to 212° , is to its expansion from 32° to 122° , as 15 to 14 ; that of olive oil in the same circumstances, as 15 to 13.4 ; of oil of chamomile, as 15 to 13 ; of water saturated with common salt, as 15 to 11.6 ; of alcohol as 15 to 10.9 ; and of water, as 15 to 4.7. Mr. Dalton having found that the dilatations of water are nearly as the squares of the temperatures reckoning from 32° , or the maximum of condensation, infers, that the law is equally applicable to all other homogeneous liquids ; and he conceives the slight deviation from this law, observed in water, arises from the unequal expansions in the mercury of the thermometer. If an instrument of this kind be so constructed as to accord with the unequal dilatations, the degrees will be smaller between 32° and 122° , than between 122° and 212° . The following table exhibits the results of Mr. Dalton's calculations for this purpose ; the first column showing the *true* divisions on Fahrenheit's thermometer, as corrected by this philosopher ; the second, the corresponding divisions on the scale as commonly constructed ; and the third representing the last with a correction, for the expansion of the glass thermometric tube.*

* New System, Part i p. 14.

32	32	32
42	39.3	39.3
52	46.6	47
62	54.44	55
72	62.55	63.3
82	71.04	72
92	79.84	81
102	89.02	90.4
112	98.49	100.1
122	108.3	110
132	118.5	120.1
142	129	130.4
152	139.9	141.1
162	151	152
172	162.4	163.2
182	174.4	175
192	186.5	186.9
202	199.2	199.2
212	212	212

From the experiments of Mr. De Luc and Mr. Dalton, a general formula has been calculated by M. Biot, by which the dilatations of all liquids that have been examined, may be found.* Let t denote the temperature in degrees of the mercurial thermometer; a, b, c , constant coefficients, which depend upon the nature of the liquid; and d_t the true dilatation for unity of volume; then

$$d_t = a t + b t^2 + c t^3$$

LXXXIX. It is obvious, then, that, according to the common construction, the mercurial thermometer does not correctly express the real temperatures of bodies, because the divisions throughout are equal, and no allowance is made for the augmented rate of expansion in the upper part of the scale, which, in relation to the lower half, is as 15 to 14. The height of the mercury, as appears by Mr. Dalton's table, is also, in some measure, influenced by the expansions of the

* Annals of Philosophy, vol. ix. p. 363.

glass tube. But this difference in mercury is much less than is observed in the expansions of spirit of wine; and it seems to be a general law, that those liquids expand the most in the upper division of the scale, the boiling points of which are lowest. Hence, as the boiling point of mercury is much higher on the scale of heat, than that of spirit of wine, the difference of expansibility is proportionally less, and in a vast number of experiments with the mercurial thermometer, in which the temperature does not approach either extreme of the scale, no essential error will be introduced. Hence, also, it will appear, that the spirit thermometer is best calculated to measure low degrees, and the mercurial high degrees of temperature.

XC. Expansion, as has been observed, constitutes the most general effect of caloric; yet there are some exceptions. Pure clay, after its water has been driven off, contracts in proportion to the heat applied; and experiments have sufficiently demonstrated, that water diminishes in volume, until its temperature is reduced to 40° Fah. but that from 40° to 32° it again expands. It has been proved that this circumstance is not owing to the contraction of the substance of the vessel which contains the liquid, but to some anomalous quality in the water itself. It is possible that the dilatation may arise from the disposition which the particles of the water acquire below 40° to assume a new arrangement. Crystallization takes place at 32° , and there may be an approximation to this at a temperature above 32° , or the action, which is to terminate in the production of a geometrical solid, may commence a few degrees above that temperature, which is necessary to a crystalline arrangement of the particles. It appears that most liquids, which, on becoming solid, assume a crystalline form, expand in volume. The fact is familiar with regard to water, and the prodigious force exerted at the moment of solidification, has been amply shown, among others, by Major Williams in his experiments at Quebec.* The

* Ed. Philos. Trans. vol. ii.

same is the case with cast iron, bismuth and antimony. But these facts can hardly be considered as exceptions to the general law, for the expansion is the consequence of a change of form, or of these bodies ceasing to exist as liquids.

SECTION II.

Fluidity.

XCI. If the caloric, applied to a solid after it has been expanded to a certain degree, be increased, the cohesion of the particles is apparently diminished, they acquire the power of moving freely over each other, and thus constitute a liquid. Although it is generally admitted that the change of a solid into a liquid depends upon the diminution of the attractive force which unites the particles, yet it is not certain that this is the just explanation of the fact. Professor Robison has shown that the effect of fluidity may be produced, even where the force of cohesion remains undiminished. It requires only a change in the form of the particles. In order that a particle of a fluid may be moved, with so much ease, from one place to another among particles of the same kind, the only circumstance required is, that all situations shall be alike indifferent; and, that this may be the case, the action of a particle must be equal in every direction at the same distance; it is of no consequence how strong the force may be, or whether it is attractive, or repellent. If the action be equal, it is obvious that no force will be necessary to move an adjoining particle in any direction, nor to retain it in any situation. The attraction and repulsion may vary according to any law, by a change of distance, but it is equal in every direction at that distance. An assemblage of such particles must have all the well known appearances of a fluid; and it may be demonstrated that a particle of such an assemblage must either be a single atom, or a sphere composed of numberless atoms, symmetrically arranged. The spherical form is necessary for fluidity, not for the reason commonly assigned, that they

may touch only in a few points, and easily slide over each other, but in order to produce an equality of action among the particles in every direction. Solidity, on the contrary, requires a very different law of action among its particles; and to form a body of this class it is only necessary that a particle attract or repel a second, more strongly in one direction than in another, at the same distance; and if the action of one particle be thus unequal, an assemblage of such particles cannot be fluid; for they will unite by some surfaces in preference to others, and their motions over each other must be unequal. The power which thus operates in causing the union of particles in a determinate mode may be that which gives to them a species of polarity.*

XCII. The point of fusion is invariably the same in the same body; ice begins to melt when its temperature is raised to 32° Fah. and it continues at that degree until the whole is converted into water. From a knowledge of this general fact, it is not difficult to fix the melting points of solids, either by the thermometer, or pyrometer. The following table, founded upon experiments, exhibits the temperatures to which different solids require to be raised, in order to become liquid.

* Black's Lectures, vol. i. note v

Cast Iron	-	melts at	-	20577° Fah.
Fine Gold	-	-	-	5237°
Fine Silver	-	-	-	4717°
Copper	-	-	-	4587°
Brass	-	-	-	3807°
Zinc	-	-	-	680°
Lead	-	-	-	594°
Bismuth	-	-	-	476°
Sulphur	-	-	-	214°
Spermaceti	-	-	-	133°
Phosphorus	-	-	-	100°
Olive Oil	-	-	-	36°
Ice	-	-	-	32°
Vinegar	-	-	-	28°
Quicksilver	-	-	-	— 39°.5
Sulphuric Ether	-	-	-	— 46°

XCIH. Some bodies, however, are not susceptible of taking on the liquid form, either because they are decomposed and their elements are made to enter into new combinations at low temperatures, or because their tendency to assume the elastic state becomes effectual so soon as the cohesion of their particles is lessened to a certain degree by the repulsive power of caloric. Thus, calomel, arsenic of commerce, &c. on exposure to heat, pass immediately into vapour, without undergoing the intermediate change of liquidity.

In a few cases, the change from a solid to a liquid form is not well defined. The body, by the application of heat, gradually softens, and the tendency to liquefaction increases with the temperature; of such bodies glass, wax, and tallow exhibit examples, and in these, it is difficult to fix with precision their true melting points. In general, however, those which crystallize have no interval between solidity and fluidity.*

XCIV. Mixtures of bodies, which are capable of acting chemically upon each other when liquid, will, on exposure to

* Dr. Thomson.

heat, become fluid at temperatures much lower than are necessary to melt either of the ingredients in a separate state. The bodies commonly known by the name of earths, e. g. silex, alumine, lime, &c. are fusible, when pure and unmixed, only in the intense heat of the oxy-hydrogen blow-pipe ; but if they be blended with each other in fine powder, the mixture may be melted in a common furnace. An alloy of bismuth, lead and tin, will melt in boiling water, but neither of these metals can be fused in a separate state below the 442° of Fah. The congealing points of liquids are also diminished by mixture, or combination with various other bodies. The disposition in water to remain liquid is increased by the addition of spirit of wine, acids, and neutral salts. The water of the ocean requires a lower temperature for its congelation, than fresh water. Sir C. Blagden has found that this liquid, containing 25 parts of common salt, may be cooled to 4° ; that solution of sal ammoniac freezes at 20° ; of Rochelle salt at 21° ; of Epsom salt at $25^{\circ}.5$; of nitre at 26° ; of green vitriol at 28° ; and of white vitriol at $28^{\circ}.6$; and that the same effect is produced by alcohol. Strong wines freeze at about 20° ; 3 parts of water and 1 of alcohol become solid at 7° ; a mixture of equal bulks, at -7° ; and of 2 parts of alcohol to 1 of water, at -11° . If 10 parts of oil of vitriol, specific gravity 1.837, be mixed with 100 parts of water, the liquid will freeze at $24^{\circ}.5$; 20 parts of acid to 100 of water, require a reduction of temperature, equal to $12^{\circ}.5$; and when the liquid contains 25 parts of acid, it will preserve its fluidity at $7^{\circ}.5$.*

XCV. Solids, when their temperature is raised to their melting points, are not at once converted into liquids. On the contrary, this change takes place slowly, unless the heat be greatly increased, and more time is required to bring them to this state, than is necessary to raise them to the temperature, at which this new form commences. It is well known, that when ice or snow is heated to 32° , instead of being immediately converted into water, it melts in a very gradual manner ; and that when in considerable masses, it may be

* Phil. Trans. for 1788, p. 125.

exposed to the direct rays of the vernal sun for some days, before it is totally liquefied. When a piece of ice is suspended in a warm room, its bulk gradually lessens, and a descending current of cool air is found by the thermometer to be formed, which continues until the whole mass is changed into water. The ice itself remains at 32° , whatever may be the temperature of the surrounding air. It appears, then, that the air loses a portion of its caloric on coming into contact with the ice, it contracts, its specific gravity is increased, and it descends. Yet the caloric, thus lost by the air, does not seem to be gained by the ice, for its temperature remains invariably the same, as is the case also with the drops of water which flow from its lower surface. It has, however, been satisfactorily proved by Dr. Black, that the ice actually receives this caloric, and that it is expended in changing it into water. This philosopher found, that it required an exposure of 21 half hours in a room, the temperature of which was 40° , to melt 5 ounces of ice, and to raise the heat of the water thus formed, from 32° to 40° ; but 5 ounces of water had their temperature augmented from 33° to 40° in one half hour; consequently, supposing each to have received the same quantity of heat in the half hour, i. e. 7° , it followed that the caloric which was received by the ice, and which was necessary to convert it into water, must have been $40 - 33 \times 21$, or 7×21 , or 147° . Now, of all this caloric, only 7° or 8° were perceptible to the thermometer; hence, it was very justly inferred by Dr. Black, that water, in passing from the solid to the liquid state, absorbs 139° or 140° of caloric, without producing any sensible effect upon its temperature.* This conclusion was confirmed by other experiments which were equally simple and satisfactory.

If a pound of ice at 32° be mixed with a pound of water at 172° , the solid will soon be melted, and the temperature of the water will fall to 32° . There is no other way of accounting for this sudden diminution of heat than by supposing that the 140° have been expended in converting the ice into water.

* Lectures, 4to ed. vol. i. p. 122.

XCVI. To the caloric, thus absorbed during the liquefaction of ice, Dr. Black has given the name of *Latent*, because, in this state, it is concealed, or incapable of exhibiting its characteristic properties; and because it is necessary to distinguish it from that which affects the thermometer, and which has been called *Free* or *Sensible*. The former has also been styled Caloric of fluidity.

XCVII. The cause, then, of the slowness with which ice is melted, is the great quantity of caloric necessary to the constitution of water. But if this caloric be actually absorbed and rendered latent, it ought to be again given out, or made sensible when water is changed into ice. The truth of this proposition was also demonstrated by Dr. Black. When water begins to congeal, whatever may be the temperature to which it is exposed, it continues invariably at 32° , until the whole is frozen. If the air be 10 degrees below the freezing point, a thermometer suspended immediately over the congealing water will stand some degrees higher, than if placed at the same distance from the bottom or side of the vessel. Hence, during this process, a stream of comparatively warm air ascends from the surface of the liquid; and it continues until the whole of the water is frozen, when the temperature of the mass, like that of any other solid, falls to that of the surrounding air. If two vessels of the same size, one containing water alone, and the other a mixture of equal volumes of water and spirit of wine, be exposed to an atmosphere, 20° for example, below the freezing point, a thermometer being immersed in each, the temperature of the one which contains the spirit will regularly descend, until it acquires that of the medium in which it is placed; but this will not be the case with that which holds the pure water; so soon as it falls to 32° , it becomes stationary, and remains at that point until the whole is converted into ice. It is obvious, then, that as the only difference which exists between the two vessels is, that the mixture in the one preserves its fluidity, while the water in the other is in the act of congelation, the cause of the uniformity of tempera-

ture in the latter must be sought for in the change which the liquid is undergoing, and, as Dr. Black had demonstrated that caloric was absorbed in the conversion of ice into water, it follows that the production of caloric in this experiment is owing to the change of water into ice.

This fact of the extrication of caloric during congelation is also illustrated by an experiment first noticed by Fahrenheit, and repeated by other chemists. Water and many other liquids in small quantities, and in a state of absolute rest, may be cooled several degrees below their ordinary freezing points, without changing their forms. The temperature of water was thus reduced by Sir C. Blagden to 21° Fah. by Mr. De Luc to 14° or 15° , and by Mr. Dalton to 5° , without producing congelation. In such cases, agitation alone, or the addition of some foreign body, or a piece of ice, causes an immediate crystallization, and beautiful plumose or radiated crystals are seen to shoot through the liquid mass. If this experiment be performed with the precaution of previously introducing into the water, a thermometer, it will be found that so soon as congelation commences, the mercury in the instrument will rise and become stationary at 32° . A quantity of caloric is thus set free, or rendered sensible, but the amount is not indicated by the thermometer, because the melting point of ice is 32° , and the excess of caloric must be expended in liquefying some of that which had just been formed. Hence it happens that, after the experiment, the mass appears as a soft solid with water in the interstices. Dr. Thomson has drawn the conclusion, from his own experiments, that for every 5° to which water is cooled below the freezing point, $\frac{1}{28}$ of the liquid will freeze by agitation.

The amount of caloric required for the liquefaction of ice, or in other words, the latent heat of water, has been differently stated by chemists. It has been estimated by Dr. Black, at 140° ; by Mr. Cavendish at 150° ; by M. M. Lavoisier and La Place, and Mr. Leslie at 135° ; by Mr. Wilcke at 129° ; and by Gadolin at 143° . The mean of these numbers is 139.4. It may, therefore, be considered as equal to 140° .

XCVIII. After Dr. Black had discovered the facts relating to latent caloric, he endeavoured to explain them upon the principle, that fluidity depended immediately, and inseparably, upon a certain quantity of the matter of heat, which was combined with the fluid body, in a particular manner, so as not to be communicable to the thermometer, or to other bodies, but capable of being again extricated by other methods, and of re-assuming the form of moveable and sensible heat.* This doctrine was also supported by De Luc and Seguin. A different view, however, was taken of the circumstances connected with fluidity by Dr. Irvine of Glasgow. It was conceived by him to be owing to the action of sensible caloric alone, and the absorption of this agent during the change of a solid into a liquid to depend upon an increase of *capacity* in the body for heat. In liquefaction, the particles of matter are apparently removed to greater distances from each other, and from the tendency of caloric to an equilibrium, it would flow into the new body and exist in it in a proportionally larger quantity. Fluidity, then, in the hypothesis of Dr. Irvine is the consequence, not of a combination of the matter of heat with the particles of a gravitating substance, but of an increase of capacity; and the change from liquidity to solidity, of a diminution of capacity. The latent and sensible forms of caloric, therefore, depend upon a cause entirely distinct from that which was assigned by Dr. Black.

XCIX. The views of Dr. Irvine were adopted by Dr. Crawford, and in his work on Animal Heat, he gives the following simple explanation of the relations to each other of capacity, temperature, and absolute heat. "The temperature, the capacity for containing heat, and the absolute heat contained, may be distinguished from each other in the following manner. The capacity for containing heat, and the absolute heat contained, may be distinguished as a force, from the subject upon which it operates. When we speak of capacity we mean a power inherent in the heated body; when we speak of the absolute heat.

* Lectures, vol. i. 4to ed. p. 144.

we mean an unknown principle which is retained in the body by the operation of this power ; and when we speak of temperature, we consider the unknown principle as producing certain impressions upon the thermometer." Much refined discussion has taken place upon the comparative merits of these two hypotheses. The principal objection against that of Dr. Irvine is founded upon the circumstance, that the mode, in which the increase of capacity is produced, has not been accounted for ; yet if the signification of the term be restricted, as has been done by Irvine, Crawford, and Murray, so as to express merely the general fact that bodies possess the power of containing a certain portion of caloric, independently of any hypothesis respecting the manner in which it exists in them, it will be found equally correct and convenient. It has, in fact, been adopted by most chemists ; but there are some who prefer the terms Specific caloric, which are applied to the amount of this principle contained in bodies in quantities peculiar to each.

C. When the fact was once established, that ice on being converted into water absorbed and rendered latent a quantity of caloric, there was every reason to suppose that the same would be found to obtain from similar changes in form in other substances. Experiments were soon made, which demonstrated the general principle, that all solids when converted into liquids absorb, and all liquids when condensed into solids evolved caloric. The following little table, from the experiments of Dr. Irvine and son, exhibits the quantity of caloric which is rendered latent as the substances become liquefied.

Spermaceti	-	-	-	-	-	-	145°
Bees wax	-	-	-	-	-	-	174°
Tin	-	-	-	-	-	-	500°
Bismuth	-	-	-	-	-	-	550°
Lead	-	-	-	-	-	-	162°
Zinc	-	-	-	-	-	-	493°
Sulphur	-	-	-	-	-	-	143°

CI. If two equal volumes of the same body, unequally heated, be mixed with each other, the resulting temperature will be the mean between the hot and the cold portion. If a pound of water at 50° , be mixed with another at 100° , the heat after they are uniformly mingled will be 75° ; a result which would naturally be anticipated, for the portions being homogeneous, their relations to caloric must be the same. But it is not so with heterogeneous bodies. If a measure of mercury at 50° be mixed with a measure of water at 100° , the heat will be as high as 80° ; on the contrary, if the water be at 50° and the mercury at 100° , the resulting temperature, instead of being 75° , will be 70° ; whence, it appears, that in the first experiment, the water loses but 20° , in heating the mercury 30° ; and in the second, that mercury parts with 30° , in raising the temperature of water only 20° . These two bodies, therefore, require a different amount of this principle, to bring them to an equality of temperature, and as the quantity of caloric which is capable of heating mercury 30° , will raise water only 20° , the relative capacities of these bodies, when equal bulks are employed, are as 2 to 3. If weights be substituted for measures, the difference is much greater, the capacity of water being to that of mercury as 28 : 1. It appears, that heterogeneous bodies of the same form, require a different amount of the caloric to raise them to the same temperature, and from the results of a great variety of experiments, it seems that the capacities of any two bodies rarely coincide. But the difference in this respect, between substances of the same form, is much less than between others in different states. Thus, the capacity of ice is less than that of water, and the capacity of steam is greater or it contains a larger amount of specific caloric, than the liquid.

CII. In estimating the capacities of bodies, it is usual to refer them to some other substance, and for this purpose, it has been found convenient to employ water, the specific heat of this liquid being considered as unity, or 1.0000. The process followed by Mr. Wilcke consisted in suspending

the article in boiling water, until it had acquired the same temperature; it was then plunged into an equal weight of water at 32° , the resulting heat being ascertained by a delicate thermometer. Water being taken as the standard, the capacity of the body was deduced by subsequent calculation. Dr. Crawford arrived at his conclusions, by mixing uniformly together, two substances of different temperatures, but of the same weight, and finding the resulting degree of heat, the change of temperature in each, proving to be inversely proportional to its capacity for caloric. In cases in which from the nature of the body to be operated upon, water could not be used, a third substance was employed, viz. powdered glass, which was added to equal but separate weights of water, and of the body, the capacity of which was to be found, until they had acquired the same temperature. The relative capacities of the water and of the substance were as the weights of glass respectively required.

Another method of estimating the capacities of bodies, is to ascertain how much ice they are capable of melting, in cooling from a certain temperature to 32° . As ice in becoming liquid absorbs a quantity of caloric, the capacity of the body must be proportional to the amount of water produced. For this purpose, M. M. Lavoisier and La Place invented an apparatus, which they called a Calorimeter. It consists of three vessels inserted one within the other, the inner one being formed of iron wire, and destined to contain the substance whose capacity is to be found. The space between this and the next vessel contains the ice to be melted; and the most external of the cavities, as well as a double cover, is filled with ice to prevent the passage of caloric from without. Connected with the calorimeter, are two tubes furnished with stop-cocks, one of them communicating with the inner cavity for the purpose of withdrawing the water by the amount of which the capacity of the body is to be estimated, and the other with the external cavity, through which the water from the ice used to prevent the ingress of caloric from without, is

removed. In performing experiments with this instrument, the temperature of the air should not be above 41° , nor below 32° . The capacities of a variety of bodies were ascertained in this way, by these distinguished philosophers. But the accuracy of their conclusions is doubted; 1. Because a current of air must almost necessarily be established, in consequence of the cavity containing the heated body communicating with the external air. 2. Because a quantity of water must be retained in the ice, by capillary attraction, by which the real amount of the ice melted will appear less, than is actually liquefied; and 3. Because from the experiments of Mr. Wedgewood, the curious fact has been ascertained, that a portion of the water, which has been found, actually reassumes the solid state as it passes through the fragments of ice, and as it is impossible to ascertain the proportion which has thus become congealed, it is equally so to discover the quantity of water first formed, M. M. Berard and De la Roche made use of a very ingenious, but complicated apparatus for the purpose of ascertaining the specific heat of some of the gases. The details may be found in the second volume of the *Annals of Philosophy*.

CIII. To account for the difference in the specific heats of different bodies, it has been supposed that some substances have a greater attraction for caloric, or can combine with a larger quantity of this principle than others, that caloric, therefore, is to be considered as an element which, like gravitating matter, can enter into combination in various proportions and form true chemical compounds.

CIV. The conclusions which appear to follow from investigations made into the subject of capacity, are, 1. That when the particles of bodies are made to approximate to each other, their capacities are diminished, when rarefied their capacities are increased. 2. That the capacity of a body depends upon its form; it is augmented as the body passes from the solid to the liquid, or from the liquid to the gaseous state; and diminished when it is reduced from an aëriiform to a liquid, or from a liquid to a solid form. 3. That the capacities of

bodies of the same form are not always inversely as their densities. 4. That when the capacity of a body is increased, the amount of caloric remaining the same, the temperature will fall, when it is reduced, the temperature will rise. 5. That to find the relative capacities of two bodies, supposing them to be mixed in equal weights but at different temperatures, multiply the weight of each body by the number of degrees between its temperature *before* and *after* mixture, the capacities will be inversely as the products. If equal *measures* be employed, the capacities may be found by multiplying the numbers expressing the capacities by weight, by the numbers denoting their specific gravities.

CV. On the principles above stated may be explained the production and the absorption of caloric in cases of the chemical union of bodies. When this combination is followed by condensation alone, or by increased density from change of form, caloric will be extricated, as is shown in the mutual action of acids and water, of oxygen and the metals, and of those elastic fluids, the union of which terminates in the formation of a solid. On the other hand, caloric is rendered latent in those cases in which the density is diminished, either by simple rarefaction, or by a change of form. When air is suddenly rarefied, its temperature falls; the production of vapour, in the same circumstances, has the same effect. Solids, while dissolving in liquids, produce cold, and the reduction of temperature is more evident, when two solids by mixture become rapidly liquefied. The phænomena of *freezing* mixtures, as they have been called, are good examples of the reduction of heat in consequence of a sudden increase of capacity. The bodies employed are the neutral salts, water, acids, pure or diluted, ice, and snow. When nitre is added in large proportion to water, the temperature sinks during the solution about 17° ; if sal ammoniac be substituted, it falls 27° , and even 37° , or from 36° to -1° when muriate of lime is employed. Five parts of a mixture of equal weights of nitre and sal ammoniac, added to 8 parts of water, cause it to fall from 50° to 11° .

Glauber's salts and concentrated acids sink the thermometer about 50° ; if the acids be diluted, the effect is still more positive, for 9 parts phosphate soda, 6 of nitrate of ammonia, and 4 of diluted nitric acid, reduce the heat from 50° to -21° . If snow be substituted for the salts, the effect of the acids is very powerful, varying, however, according to the nature of the acid, and the degree of dilution. By previously cooling the materials by other mixtures, Mr. Walker reduced a spirit thermometer in nitric acid and snow, to -91° Fah. Snow and solid saline substances constitute some of the most convenient and efficient of the freezing mixtures; with common salt, the temperature falls from 32° to 0 ; with pure crystallized potash, from 32° to -53° ; and with muriate of lime, from 5° to -56° .* Some precautions are requisite to obtain the full effect of these mixtures. The vessels should be no larger than are necessary to contain the materials; they should be formed of imperfect conductors of caloric; the salts should have been recently crystallized and in fine powder; the snow should be perfectly dry; and in cooling them before mixture, care ought to be taken not to reduce their temperature so low as to prevent their mutual action, when they come into contact.

CVI. Notwithstanding the firm foundation upon which the generalizations of Drs. Crawford and Irvine on the subject of Capacity, appeared to rest, the progress of chemistry has brought to light many facts which are adverse to some of their conclusions. The disengagement of caloric is not always the result of increased density; nor is its absorption invariably the consequence of a change of form, from solid to gaseous matter. Facts, which have been already stated, (XXXV.) are opposed to the commonly received idea of the relations of

* Mr. Hutton of Edinburgh has succeeded in freezing very pure spirit of wine, and has placed its congealing point at about -110° Fah. His method has not been published, but the great reduction of temperature may perhaps have been produced by the sudden rarefaction of highly condensed air, previously cooled to a very low degree of the thermometer, by some of the freezing mixtures.

temperature to capacity, and of specific heat to the density of a body. At present, these facts are to be considered only as exceptions, but it is very probable, that when this subject has been more completely investigated, they may become so numerous as to render a modification necessary, of the original doctrines of Black, Crawford, and Irvine.

CVII. The unequal action of caloric in producing an increase of volume and a diminution of specific gravity in the fluids, both elastic and non-elastic, gives rise to motions which must have an important influence upon the temperature of different parts of the globe. Currents must thus be established, both in the ocean and the atmosphere. In tropical countries, the air coming into contact with the earth, which is heated by the solar rays, has its temperature increased, and in consequence of its expansion must rise, portions of an inferior temperature rushing in to supply its place, become warmed, and thus an ascending current of heated air is formed, which passes from the equator toward the poles, while the inferior stratum of colder air flows from higher latitudes toward the tropics. The former loses, and the latter acquires heat in its progress, and the caloric is thus more equally distributed. On the same principle, currents will be formed in the ocean. The absorbing power of water, according to the experiments of Mr. Leslie, is great, and from the action of the sun's rays and the winds which sweep over it, the surface of the sea, in the equatorial regions, must be comparatively warm. From the influence of the trade winds, currents are established, the principal one of which is the Gulf stream, extending from the bay of Mexico, along the shores of the U. S. to the banks of Newfoundland, and turning off towards the Western islands. The temperature of the waters of this stream is higher than the air, which blows over it, and of the ocean, through which it passes. The following table exhibits the results of experiments made by a Gentleman,* while crossing it in the latitude of Charleston, S. C. in January, 1817.

* Capt. Thomas Curtis of Boston.

Day.	Long.W.	Lat. N.	Temperature.		
			Air.	Sea.	
20. 10. A.M.	77.35.	32.23.	52 ^o	67 ^o	Entering the Stream.
Merid.	" 23.	" 25.	51 ^o	71 ^o	
21. 2. P.M.	" 14.	" 25.	52 ^o	72 ^o	
4.	" 05.	" 25.	52 ^o	72 ^o	
5.	76.59.	" 26.	52 ^o	73 ^o	
8.	" 34.	" 30.	59 ^o	72 ^o	
Midnight.	76.00.	" 36.	64 ^o	72 ^o	
22. 8. A.M.	74.52.	" 46.	68 ^o	72 ^o	Leaving the Stream.
Merid.	" 17.	" 56.	70 ^o	67 ^o	
4. P.M.	73.49.	33.00.	69 ^o	67 ^o	Out of the influence of the current.
23. 8. A.M.	72.13.	" 24.	69 ^o	65 ^o	
Merid.	71.55.	" 27.	69 ^o	65 ^o	

Subsequent experiments of this Gentleman confirmed the observations of Mr. Williams, that the arrival on soundings may be ascertained by the fall in the temperature of the water. The heat communicated to the air which comes into contact with the Stream must be very considerable, for if the calculation of Count Rumford be correct, each superficial foot of water, in cooling *one* degree, gives off a quantity of caloric, sufficient to heat a superincumbent stratum of air 44 times as thick as the depth of the water, *ten* degrees. A counter current of colder water probably flows towards the equator, and thus masses of different temperatures become mingled by currents and the swell of the ocean, so that something like an equalization of heat is preserved. The congelation of water has a still greater effect in heating the air immediately in contact; for during this change of form, its specific caloric, which amounts to nearly 140°, must be rendered sensible. When, therefore, the ocean in high latitudes begins to freeze, this caloric of fluidity will be given out, and, according to Rumford, "the heat evolved in the formation of each superficial foot of ice would be sufficient to raise the temperature of a stratum of incumbent air, 2220 times as thick as the ice, 28°, or from the temperature of freezing water, to that of the 50° of Fahrenheit's thermometer."*

* Essay xi, p. 302. Amer. ed.

SECTION III.

Vaporisation.

CVIII. When heat is applied to a liquid, its volume and temperature rise to a certain point, beyond which its particles acquire a repulsive energy, and thus form an invisible, elastic, and compressible fluid, which is called vapour. The production of vapour is exemplified in the familiar process of the boiling of water. Caloric being applied to this liquid it first expands, motions are observed to take place in it, the whole is successively brought into contact with the heated surface of the vessel, and when it is raised to the 212° , the water at the bottom being converted into vapour, rises through the mass in the form of bubbles. The whole may be thus vaporised. The noise observed previously to the commencement of ebullition called *simmering*, is probably owing to the production of small portions of vapour at the heated surface, and their condensation by the cooler liquid above; by this condensation, a vacuum must be formed at the points where the vapour was formed, and the water, pressing into it with force, produces sound.

CIX. The point at which vapour is formed varies with the nature of the liquid, but it is invariably the same, under the medium pressure of the air, in the same body. It is called the boiling point. Thus, ether will boil at 96° Fah; spirit of wine at 165° ; water at 212° , and quicksilver at 672° . This fact, at least respecting water, was discovered by Mr. Hooke, and it has been found to obtain among all liquids; which, to be converted into vapour, require the direct application of heat.

CX. Vapours which are formed from liquids are invisible. If a quantity of ether be put into an exhausted receiver, the vessel will be immediately filled with its vapour, but its transparency will not be impaired. The vapours, however, of some solid substances, such as iodine and indigogene, have colour, and are, consequently, capable of reflecting some of the rays

of light. In general, they are seen only in consequence of their partial condensation, by which their peculiar constitution is changed. This invisible state of the vapours is probably owing to their extreme rarity; their particles being placed at much greater distances than they were before their change of form. The volume of water, in passing from the liquid to the elastic form, according to the experiments of Dr. Black and Mr. Watt, is augmented about 1800 times. It is this great enlargement of bulk which renders the confinement of water under exposure to heat so dangerous, and which is frequently the cause of destructive explosion in the boilers of steam-engines, in the process of boiling linseed oil and in founderies. It has sometimes happened, that a person by carelessly spitting in a copper foundry has occasioned an explosion which has destroyed the whole building.*

CXI. The reason why liquids require to have their temperatures raised to certain points in order to be converted into vapours is supposed to be the pressure exerted by the atmosphere, which operates as an antagonist power to expansion. This pressure varies from $14\frac{1}{2}$ to 15 pounds upon every square inch of surface, and it is not until so much caloric has been introduced into a liquid as that its expansive energy shall be equal or superior to the resistance, that vapour is formed. This resistance, as has been observed, is surmounted in ether at 96° ; in water at 212° , and in alcohol at 165° . If this pressure be in part removed, the boiling points of these liquids will stand proportionably lower on the thermometrical scale. Thus, it was found by Saussure, that water boiled on the summit of Mont Blanc, the pinnacle of the Alps, at $187^{\circ}\frac{1}{2}$ Fah.† This fact affords a simple and perhaps satisfactory method of taking altitudes, and it has been employed with success for this purpose. This process may be imitated by the air-pump. Water in the exhausted receiver of this machine may be made to boil until its temperature is reduced to 67° ; alcohol to 30°

* Black's Lectures, vol. i. p. 146.

† Voyages dans les Alpes, t. iv. p. 202.

or 31° , and ether to -47° . It has been proved by Professor Robison, that the difference in the boiling points of all liquids in the open air and *in vacuo* is the same, being about 145° .* Vapour, thus formed in the receiver of an air-pump, will be condensed when the air is re-admitted. Take a glass tube 6 inches in length, open only at one end, pour into it water to the depth of 5 inches and fill the remaining inch with ether, invert the tube in a vessel of water, place it upon the plate of the pump, and exhaust the air, the ether will be vaporised, the vapour will force out the water and occupy the whole tube; if the air be again admitted, the vapour will be condensed and the water will again rush into the space. Pour into a glass flask having a stopcock fastened into it, a quantity of water, not so much, however, as to fill it, cause the water to boil and, while boiling, remove it from the lamp and turn the stopcock; in a few moments it will cease to boil; if moistened paper, or any cold body be then applied to the upper surface, ebullition will again commence, and in this way it may be continued at pleasure for some time. The flask is filled with vapour which acts the part of the atmosphere, and by condensing it, the pressure on the liquid is taken off and vapour will again be formed. If after the flask has been cooled it be put into water and gradually heated, the liquid within will boil sooner than that by which it is surrounded.

CXII. On the contrary, it requires a higher temperature to cause liquids to boil, when their vapour is confined, than when exposed to the air. This fact is proved by Papin's Digestor, which is a cylindrical vessel of copper or iron, bound with hoops, and having a lid secured by screws. Water being put into it and its lid screwed on, it is set on the fire; the temperature gradually rises, and when at 212° , a portion of water is vaporised, but, as the vapour cannot escape, it reacts on the liquid by its elasticity and, for a time, prevents the further formation of steam; as the heat continues to be applied, the tendency of another portion to rise in vapour

* Black's Lectures, vol. i. p. 151.

overcomes the resistance to its expansion and a second quantity is formed ; so that every successive quantity of vapour requires an higher temperature for its formation, until the heat of the water amounts to more than threetimes its ordinary boiling point. It may thus be made to melt tin and lead. The elasticity of the vapour, however, is regulated by a valve, which permits the escape of a portion of the steam when its further confinement might be dangerous. This machine was introduced into notice as a culinary utensil ; for, in consequence of the high heat and the strong pressure of the vapour, many of the parts of animals, which are not employed as food, from the difficulty of dissolving them, such as ligaments, cartilages, tendons, skins, &c. were found to be reduced in a short time to an uniform mass of nutritive jelly.

CXIII. The elasticity of all vapours, when formed from liquids boiling in the open air, is just equal to the pressure of the atmosphere, or equivalent to 30 inches of mercury in the barometrical tube. It has been shown by Mr. Dalton, that if the expansion of mercury in the thermometer be in the ratio of the square of the temperature, the force of the vapour of water, by equal increments of heat, will be in geometrical progression. The ratio of the progression, he finds to be 1.321. But as vapour is formed at temperatures below the boiling point, it will support proportional parts of the 30 inch column, the amount, however, depending upon the tendency of the liquid to assume this form. Thus, he has found that at 60°, the resistance of the vapour of ether is equivalent to 12.13 inches ; of liquid ammonia to 4.3 inches ; of water to 0.524 of an inch, and of liquid muriate of lime to 0.26 of an inch. The researches of this philosopher at length led him to the general law, that the elasticity of every other vapour is precisely the same with that of water, at the same distance from its boiling point. Thus, water boils at 212° ; the resistance of its vapour at 182°, or 30° below its boiling point, is equal to 15.86 inches of mercury. Alcohol boils at 165°, and the elasticity of its vapour 30° lower, is likewise 15.86 inches.

Hence, if the boiling points of liquids be known, it is easy to calculate the elasticity of their vapours at any temperatures, by referring to the tables of Mr. Dalton.

The following are some of the results of the experiments and calculations of Mr. Dalton on the force of the vapour of water at different degrees of the thermometer.

Temp.	Elast.	T.	E.	T.	E.
— 40	.013	120	3.33	270	77.85
— 30	.020	130	4.34	280	88.75
— 20	.030	140	5.74	290	100.12
— 10	.043	150	7.42	300	111.81
0	.064	160	9.46	310	123.53
10	.090	170	12.13	311	124.69
20	.129	180	15.15	312	125.85
30	.186	190	19.	313	127.
40	.263	200	23.64	314	128.15
50	.375	210	28.84	315	129.29
60	.524	212	30.	316	130.43
70	.721	220	34.99	317	131.57
80	1.00	230	41.71	318	132.72
90	1.36	240	49.67	319	133.86
100	1.86	250	58.21	320	135.
110	2.53	260	67.73	321	136.14

Mr. Dalton has thus found, that the elasticity of steam is doubled for every 40° ; for at 252° it is capable of sustaining 60.05 inches of mercury. From this view of the relation of the force of vapour to temperature, it must obviously be considered as an instrument of great power, and capable, when duly regulated, of producing astonishing effects. The steam engine is perhaps the most magnificent machine ever invented. It is, as justly observed by Dr. Black, a gift of philosophy to the arts. Upon the common construction, in which the pressure is equivalent only to the weight of the atmosphere, it may be managed with ease and employed with security. But the high pressure engines, as they have been termed, or those in which the elasticity is increased by load-

ing the valves with weights, act with much greater power, and require a proportional increase of strength in the boiler to prevent explosion. Most of the accidents of the kind which have occurred in this country, have arisen from the use of additional pressure upon the valves.

CXIV. The specific gravities of vapours differ from each other, according to the nature of the liquids from which they are formed. The following table exhibits the boiling points of various liquids, and the specific gravities of their vapours, from the experiments of M. Gay Lussac, the specific gravity of air being 1.*

	Boiling point.				S. G. Vapour.
Water - - -	212°	-	-	-	0.6235.
Hydrocyanic acid -	79°.7	-	-	-	0.9476.
Alcohol - -	173°	-	-	-	1.6030.
Muriatic ether - -	52°†	-	-	-	2.2190.
Sulphuric ether -	96°	-	-	-	2.5860.
Sulphuret of carbon -	116°	-	-	-	2.6447.
Oil of turpentine -	314°‡	-	-	-	5.0130.
Hydriodic ether - -	148°	-	-	-	5.4749.

These results confirm the observations made by Theo. De Saussure in 1808, respecting the vapour of water, alcohol, and ether, but they are at variance with the general law which he has stated, that the specific gravities of vapours are in the ratio of the volatility of the liquids from which they are produced. He remarks that water at a given temperature is less evaporable than alcohol, and alcohol than ether. The elastic vapour of water is lighter than that of alcohol; and the vapour of alcohol is lighter than that of ether. The specific gravity of elastic vapours, then, at equal temperatures, appears to be in the ratio of the volatility of the liquids which furnish them. The heaviest elastic vapours are produced by bodies which, in similar circumstances, are the

* Thomson's Chemistry, vol. i. p. 100. 5th ed.

† Thenard.

‡ Dr. Thomson.

most volatile.* But it is obvious, that the ratio between the volatility of liquids, and the specific gravity of their vapours, is applicable only to the three compounds which he has mentioned; for the density of the vapour of hydrocyanic acid, which is formed at 79° , is much less than the densities of those of alcohol, of sulphuric ether, and sulphuret of carbon, which are produced at higher temperatures; and the specific gravity of the vapour of oil of turpentine, according to Dr. Thomson, is greater than that of water, which does not require so much heat for its formation. Yet the subsequent observation of Sausure may be true, though it appears at first view rather singular, that supposing it were not a fact that gases mix uniformly with each other, but were arranged in the order of their specific gravities, then the vapours which belong to the least volatile bodies, as the earths and metals, would be those that would occupy the highest strata in the atmosphere, supposing its temperature uniform.

CXV. During the conversion of a liquid into vapour, caloric is absorbed, or rendered latent. This fact was ascertained by Dr. Black. Water requires about six times the space to be completely converted into steam, that it does to be raised from the temperature of 50° to that of 212° . Hence, presuming that it receives caloric equally fast during the whole of the ebullition, and knowing that the temperature of the vapour is no higher than that of the boiling liquid, it will follow that this caloric, on the supposition that it is material, must exist in and be essential to the constitution of the vapour. A quantity of water was found by Dr. Black to be heated from 50° to 212° in 4 minutes, and in 20 minutes more it was entirely dissipated in steam. It must, therefore, have received 162° of heat every 4 minutes, and, consequently, the whole amount was $162^{\circ} \times 6 = 972 - 162 = 810^{\circ}$, or 810° must have become latent as the water was converted into vapour.

Water was heated in Papin's Digestor to 400° ; on opening the valve, the vapour rushed out with great violence and

* Nicholson's Journal, vol. xxi. p. 336.

a shrieking noise for 2 minutes, at the same time the temperature both of the water and the steam fell to 212° . One fifth part of the water was vaporised. Now what became of the 188° which suddenly disappeared on the opening of the vessel? It must have been carried off by the steam which was formed; but as only $\frac{1}{5}$ of the water was vaporised, this vapour absorbed the 188° of the five portions of water; whence it appears, that the water, during its change of form, rendered latent $188 \times 5 = 940^{\circ}$ of heat. If one part of steam at 212° be condensed by 9 parts by weight of water at 62° , the temperature of the liquid will be raised to $178^{\circ}.6$; each ninth part of the water, therefore, must receive $116^{\circ}.6$ of heat and $116.6 \times 9 = 1049^{\circ}.4$, the amount of caloric lost by the steam in its conversion into water, from which subtract $33^{\circ}.3$ in temperature lost by the steam and the result will give rather more than 1000° for the latent heat of watery vapour.

The mean of the experiments of Dr. Black and Mr. Watt, of Lavoisier and of Count Rumford, give to water 980° of specific caloric.

CXVI. The reduction of temperature, or apparent loss of caloric during active vaporisation, is demonstrated by a variety of facts. If water, at the temperature of 200° , be placed under the receiver of an air-pump and the air be exhausted, it will boil and at the same time lose its caloric much more rapidly than an equal bulk of water, heated to the same degree and exposed to the air. Immerse the bulb of a thermometer in ether; place the vessel upon the table of an air-pump and exhaust the air, the ether will soon boil, or in other words, a portion of it will be vaporised, and if the exhaustion be continued the temperature will sink below zero. On substituting a thin glass tube containing water, the liquid, by the same process, may be congealed. If the bulb of a spirit thermometer be surrounded with muslin, moistened with the liquid called sulphuret of carbon, the temperature in the same circumstances will sink to -60° , and Dr. Marcet affirms even to -80° . In all these experiments, the sensible heat of the

liquids, or of the instruments, is converted into the latent or specific caloric of the vapour.

CXVII. Vaporisation proceeds in the ratio of the temperature and the extent of surface. In those processes, therefore, which require a rapid formation of vapour, the shape of the vessel most favourable to the operation is that in which the depth is small, while the superficies are extensive. This fact is of much importance in the art of distillation, which consists in separating substances from each other, that require different temperatures to be converted into vapour. Distillation has been divided into two kinds, the dry and the humid. To the former are often applied the terms sublimation and volatilization. The process is conducted in close vessels consisting of common flasks, matrasses, large globular receivers, and covered crucibles. Thus, camphor is purified by being exposed to heat; it rises in vapour and is condensed in its pure state, upon the superior surface of the vessel in the form of a dense crystalline solid. Flowers of sulphur is this substance purified by sublimation from roll brimstone; sal ammoniac, flowers of benzoin, salt of hartshorn, &c. are by the same method separated from the impurities with which they may have been mixed.

In humid distillation a liquid is to be separated from others with which it is mixed, and for the most part the apparatus required is somewhat more complicated. The most simple and the one most commonly employed by the chemist, consists of a retort, connected with one or more globular receivers immersed in water to facilitate the condensation of the vapour. The retort is a conical vessel of glass bent at a right angle about one third of its length from the largest extremity. It is divided into body and neck; when it has but one orifice, it is said to be plain, and tubulated when a second is added at the superior part of the body. Receivers are also plain or tubulated; but if a tube be attached to one of the orifices, it is called a quilled receiver. The disposition of this apparatus is perfectly simple and convenient.* Distillation

* Plate iii. fig. 7.

in the large way is conducted upon the same principle, but the vapour is transmitted through a spiral tube called the worm, which is contained in a large vessel surrounded by cold water.

The Alembic, an apparatus often employed for the purpose of separating a volatile oil from the more fixed parts of the vegetable in which it is contained, consists of a body and a head or capital, having a groove at the inferior part from which proceeds a tube opening into a vessel of any kind. The vegetable with a quantity of water is put into the body and exposed to heat. The oil passes over and is condensed with aqueous vapour, the mixed liquid flowing into the vessel beneath the tube. It is afterwards poured into the separatory funnel, where, in consequence of the difference in their specific gravities, the oil separates from the water, and, by means of the stopcock, may be readily obtained in a pure and unmixed state.*

In some experiments, it is necessary to make use of a very complicated apparatus, which is known by the name of its inventor, Woolf.† It is constructed upon the principle of promoting the union of elastic fluids or vapours with liquids by subjecting them to pressure. It is ingenious, but consists of too many parts to be convenient; hence, various methods have been proposed to simplify the arrangement, among which may be mentioned those of Dr. Murray,‡ and Dr. Coxe.§

The heat necessary in the various processes of distillation may be applied either directly to the vessel, which method has been called naked distillation; or through the medium of the sand, the vapour, or the salt water bath. The sand bath is an indispensable instrument in a laboratory. It is capable of affording a strong heat, its temperature is gradually raised, and the danger of injuring the vessels deposited in it is very small. It consists merely of a pan or reservoir, containing sand, placed over a furnace; and the most convenient vessels

* Plate iii. fig. 8. † Plate iv. fig. 1.

‡ System of Chemistry, vol. i. p. 241.

§ Annals of Philosophy, vol. i. p. 68.

for performing the operation of active vaporisation, when the volatile products are not required, are Wedgewood's evaporating basons and capsules of thin glass. An uniform heat may be obtained by immersing the vessel containing the materials for distillation, in water and gradually raising its temperature to the boiling point; it cannot, of course, exceed 212° . If a heat a few degrees higher be required, it may be obtained by the use of a solution of common salt.

CXVIII. It has been observed, that many liquids are capable of assuming the form of vapour at temperatures much below their boiling points; and that the force of their vapours may be, and has been measured. This effect takes place on exposure to the air. Water thus situated diminishes in bulk and gradually disappears. The process, by which the water is vaporised, is called *Evaporation*. All liquids, however, are not the subjects of this change, and the fat oils, quicksilver, many of the acids, &c. may be freely exposed without a consequent diminution in volume. Evaporation is not confined to liquids; for all those solids which are volatile, such as salt of hartshorn, camphor, and the concrete essential oils, diffuse around their peculiar odours and gradually waste away. Water in the state of ice and snow also evaporates.

CXIX. The rapidity, with which a liquid is evaporated, is proportional to the dryness, temperature, and motion of the air, and to the extent of surface exposed. Mr. Dalton ascertained that at the temperature of 180° , the quantity of water evaporated was $\frac{1}{2}$ of that which was vaporised at 212° ; at 164° it was $\frac{1}{3}$; at 152° $\frac{1}{4}$; at 144° $\frac{1}{5}$, and at 138° $\frac{1}{6}$; and he drew the conclusion that in general, the quantity of water evaporated in a minute, at any temperature, is to the quantity evaporated from the same surface at 212° , as the force of vapour at the former is to its force at the latter temperature. Hence, the force of vapour at any given degree of heat indicates the quantity of vapour which may be formed.

CXX. The quantity of water annually evaporated from the surface of the earth must be very great, when we consider

that it is the only source, so far as we know, of the copious dews and rains which fall from the atmosphere. Supposing the average quantity evaporated in one year to amount to 35 cubic inches, the whole amount will be equal in bulk to 94,450 square miles; which water, says Dr. Thomson, if it existed at one time in the air, would increase its mass by about one twelfth, and raise the mercury in the barometer nearly 3 inches. But as rain probably falls on some part of the earth every day, this can never happen.

CXXI. The air, then, even in its dryest state, contains a portion of aqueous vapour, which at the temperature of 165° has been estimated at $\frac{1}{56}$ of its volume; but it is transparent and invisible. It becomes apparent only by a partial condensation, its constitution at the same time suffers some change, and it is then commonly known by the name of cloud, mist, or vapour. If the particles of mist consisted of solid drops of water, they would fall through the air with a velocity equal, according to Mr. Robison, to 10 feet in a second; and a cloud of solid drops would always exhibit a rainbow, when placed opposite to the sun. But vapour is generally lighter than the lower stratum of air, and in the form of clouds it floats along horizontally to great distances from the places at which it was formed. Derham first suggested the idea that the particles of falling vapour are vesicular, and his opinion was confirmed by Saussure, who saw and examined some of the vesicles in the higher Alps. They may also be seen, in favourable circumstances, in the steam of a variety of liquids; and as Mr. Robison has remarked, the steam exhibits halos peculiar only to vesicles.* Of the nature of the elastic fluid contained in these shells of water, and of their modes of formation, we are entirely ignorant; but it is probable, that when they burst, the thin films of water collect, form drops, and fall in rain. It is possible that the formation of rain may be influenced by the concussion and vibration of the air in which these vesicles are floating, and that the increase of rain in a

* Black's Lectures, vol. i. note 6.

thunderstorm immediately after a flash of lightning may be as satisfactorily accounted for on this principle, as upon the perfectly hypothetical notion of the combustion of oxygen and hydrogen in the higher regions of the atmosphere.

As evaporation is proportional to the temperature and dryness of the air, more aqueous vapour must exist in it in the hot and dry weather of summer, than in the cold and humid atmosphere of winter. This, in fact, appears to be the provision made by nature for the frequent showers which are required by plants at this season. How this aqueous vapour is converted into rain, we know not. It is probable that reduction of temperature in the air and a change in its electrical states have an important influence; but we are yet ignorant whether these are the only efficient causes. In fact, little knowledge has yet been acquired of the causes of many of the phenomena of meteorology. It is not yet demonstrated how water rises in the atmosphere, in what state it exists, or why it is condensed. Still less is known of the real influence of electricity in promoting or preventing these changes; and of the origin of meteors and aërolites we are profoundly ignorant.

Mr. Howard, who has paid much attention to the natural history of the clouds, is the only person who has attempted to systematize his observations on this subject.* He has divided them into classes, which constitute the basis of the work of his commentator, Mr. Forster.†

CXXII. During spontaneous evaporation, the temperature of the liquid and of its vapour is always lower than that of the air, or of the bodies by which it is surrounded. If a few drops of ether be poured into the hand, a distinct sensation of cold will be perceived. Surround the bulb of a thermometer with muslin, dip it in the same liquid and expose it to a current of air, the ether will rapidly evaporate and the mercury in the tube will sink many degrees. If water, contained in a

* Nicholson's Journal.

† Researches about Atmospheric Phenomena &c.

small and thin glass tube be substituted, it will soon be frozen. Water while evaporating has its temperature reduced 4° , or 5° ; alcohol nearly 20° , and ether 60° . By taking off the pressure of the air, this process is proportionally accelerated, and if means be employed to remove the vapour as it is formed, intense degrees of cold may be produced. Upon this principle may be explained the decided results of Mr. Leslie's fine experiments. He ascertained that, by putting into the receiver of an air-pump a substance which powerfully attracted aqueous vapour, e. g. sulphuric acid, water might at any time be frozen solid. He has in this way succeeded in congealing even quicksilver, which requires a reduction of temperature equal to -59 . By applying this process to the cooling of the air surrounding his apparatus in the receiver, the effects were still more positive; and in one experiment a spirit thermometer sunk no less than 180° ; hence, supposing the temperature of the instrument, when first employed, to have been 60° , the cold must have been equal to -120° , the greatest reduction of temperature that has yet been known. The use of the sulphuric acid is to withdraw the aqueous vapour, which by pressure on the surface of the water would proportionally retard the process of evaporation. As sulphuric acid is inconvenient in many respects, Mr. Leslie has proposed other substances, the best of which are the dry powder of decomposed whin stone, and parched oatmeal. The details of Mr. Leslie's process may be found in the Supplement to the *Encyclopædia Britannica*, article Cold.

The effect of rapid evaporation in reducing the temperature of the remaining liquid is also beautifully illustrated by an instrument invented by Dr. Wollaston, and from its office called the Cryophorus or Frost-bearer. It consists of a glass tube from 12 to 18 inches in length, having a bulb blown at each end; before it is closed, a quantity of water is introduced sufficient to occupy nearly one half of one of the bulbs; the air is then driven out by heat and the instrument is sealed. A vacuum is thus formed; or, the only elastic

fluid it contains is the vapour of water. The bulbs, with a small part of the stem, are bent nearly at right angles with the body of the tube. When the empty bulb is immersed in a freezing mixture, the aqueous vapour is condensed, and all pressure upon the water being thus removed, vaporisation goes on so rapidly, that the water in the other bulb will soon become solid. This effect will take place even where the distance between the bulbs is 2 or 3 feet.*

In all the examples just mentioned, the reduction in temperature is the consequence of the change of form in liquids. They become vapours; their capacities for caloric are increased, and this principle is rendered latent. The specific heat of aqueous vapour is to the specific heat of water as 1.550 : 1.000.

CXXIII. These principles being established, it is easy to apply them to the solution of many natural phænomena, and of many of the operations of art. We perceive the effect of evaporation in reducing temperature, and can account for the refreshing coolness experienced after showers in hot weather; the operation of the rain being two-fold, first, in abstracting heat from the air and the earth, and subsequently, reducing the temperature by evaporation. The deposition of dew and the formation of mists and fogs at night, take place from the difference of temperature in the air at different periods of the day. The air takes up a quantity of water proportional to its temperature. At night the earth loses a part of its heat by a process which will be described under the head of *radiation*, becomes cooler than the air, and diminishes its power to retain moisture; hence, a quantity of water is deposited in the form of *dew*. In the human body there exists a provision for the constant evolution of the caloric, which is necessary to the due performance of its functions. But this caloric might occasionally accumulate to such a degree as to be incompatible with life, unless some antagonist process were found to regulate the temperature. This is the case, and cu-

* Plate iii fig. 6.

taneous exhalation may be supposed to constitute this process. At all times during health there is a stream of insensible and invisible perspiration passing from the surface of the body, by which its temperature is preserved equable and moderate. In hot weather, the skin is moistened with sensible perspiration, and the evaporation of this fluid is the provision made by nature to enable us to withstand her strongest heats. That this evaporation has the effect just described, appears to be proved by the celebrated experiment of Sir Joseph Banks, Sir Charles Blagden, and Dr. Fordyce, who remained in a room for some time heated to 260° , or 28° above the temperature of boiling water. The first effects were a sensation of burning and a difficulty of respiration; but so soon as a copious perspiration appeared upon the surface of the body, these feelings subsided; and thermometers, repeatedly applied to different parts, never rose higher than 3° above the natural temperature of the human system.

The knowledge of the fact, that heat is reduced by the evaporation of liquids, is often applied to the purposes of comfort or luxury. In warm climates, the apartments of the inhabitants are sometimes lined with plants, upon the thick and luxuriant foliage of which water is from time to time sprinkled; the dry and warm air in passing over them occasions a rapid evaporation, and diffuses a grateful coolness. Liquids are also cooled by putting the vessels which contain them into bags, suspending them in the shade, and moistening them occasionally with water. They are kept in a swinging motion, evaporation is accelerated and cold produced. The porous filtering stone vessels, used in warm climates, allow water slowly to percolate through their interstices, until it reaches the outer surface; it is then rapidly evaporated, and part of the caloric required for the constitution of the vapour is derived from the vessels themselves; hence, the liquids they contain become comparatively cold. In warm weather, insular situations are cooler than those which are inland.

CXXIV. The cause of evaporation and the mode in which vapour exists in the air have been subjects of much curious speculation and experiment. No less than three theories have been formed to account for this phænomenon. The first was that of Dr. Halley, or perhaps more positively of Le Roy, which was supported among others by Dr. Black and Dr. Franklin. It supposes that the rise of water in the air is owing to the mutual attraction between them; that water is dissolved in air precisely as salts are dissolved in water, and that the quantity at any time taken up, is proportional to the temperature and previous degree of saturation. M. Berthollet, who favours this hypothesis, considers it as an example of loose affinity, and has given to this kind of action, the name of *dissolution*.

In the second hypothesis, which is that of Saussure, water is supposed to be raised into the air by the sole agency of caloric, but after it arrives there to combine chemically with its particles.

The third is that of Mr. Dalton. He infers, that the watery vapour is entirely independent of the air, and in no way affected by the proximity of its particles; or as he has stated the hypothesis, "Water at every temperature is convertible into vapour by the operation of caloric alone; the vapour thus formed, exists in the air in a distinct state, neither attracted nor repelled by the other gases, but supporting itself by its own elasticity; the quantity of it present at any time being dependent on the temperature and the amount of the pressure exerted by the quantity of vapour already formed."

Such are the hypotheses respecting the cause of evaporation, and their number and the objections which may be urged against each, are sufficient proofs that the knowledge acquired on this subject is neither sufficiently accurate nor extensive to allow of the formation of a well grounded theory. The hypothesis of Mr. Dalton is characterised by great simplicity and elegance, and is not inferior to that of Dr. Halley in plausibility. The examination, however, of their comparative mer-

its would be mis-placed in a work of this kind, and we must refer the reader to the works mentioned in the margin, for further knowledge upon this mysterious process.*

CXXV. In order to measure relative degrees of moisture in the air an instrument has been invented, called the Hygrometer. The general principle upon which it is constructed, is founded upon the fact that the length of bodies which absorb moisture, is varied according to the quantity of water present. For this purpose, horse-hair, catgut, straw, &c. have been employed, one end being connected with an index moving along a graduated arc. Mr. Leslie, by an ingenious method, has converted his differential thermometer into an hygrometer. These methods, however, are not much to be depended upon, and at present the indications of this instrument are of little value in Meteorology. As the quantity of vapour in the atmosphere varies at different temperatures, and as there is no certain mode of depriving air of all its moisture, it is difficult if not impossible by any simple and convenient method to determine the proportion of the vapour in a given volume. Saussure has inferred from his experiments, that an English cubic foot of air, at the temperature of 66° , when saturated, contains 8 grains troy of water, or $\frac{1}{87}$ of its weight of vapour.† By Mr. Dalton, the medium quantity is supposed to amount to about $\frac{1}{70}$ of the bulk of the atmosphere; and by Sir H. Davy to $\frac{1}{50}$ of its volume at the temperature of 65° .‡

CXXVI. The uses to which steam or the vapour of water is applied are numerous and important. It is the moving power of the steam-engine, and operates as an antagonist force to the pressure of the air. It is employed to communicate warmth to apartments, being conveyed from a boiler through metallic tubes to the place where it is required. In conse-

* Black's Lectures, vol. i. Franklin's Works, vol. ii. Berthollet's Chemical Statics, vol. i. p. 332. Murray's Chemistry, vol. ii. note F. Thomson's Chemistry, vol. iii. p. 436. 3d ed. Dalton's Chemical Philosophy, part i. p. 150.

† Essais Sur l'hygrometrie, p. 99.

‡ Elements, p. 188.

quence of the great quantity of caloric, necessary for its constitution, it increases the temperature of bodies by its condensation, and hence it is used in drying gun-powder, in heating water for baths, and in bleaching cloths. Its use for culinary purposes is probably familiar.

SECTION IV.

Of the modes in which Caloric is propagated.

CXXVII. When two bodies unequally heated are brought into contact, one loses and the other acquires caloric, until an equilibrium of temperature is produced. In this case, the caloric is said to be conducted from the warmer body; and the property, by which the colder body receives and successfully propagates different portions of caloric, is called the *Conducting power*. If a hot ball be suspended in the air, and the hand be made to approach horizontally within a certain distance; or if the hand be placed below, but not in contact, we shall have the perception of heat. When the heated body is suspended in a vacuum, it gradually loses its excess of caloric and falls to the temperature of surrounding substances. In such circumstances, the particles of caloric are supposed to be thrown off in all directions from the heated surfaces toward those which are colder and at a distance, and this action is termed the *Radiation* of heat. Caloric then appears to be propagated, and an equilibrium of temperature to take place in two ways, and we shall now review the phænomena which belong to each of these modes.

1. *Conduction* of Heat.*

CXXVIII. When caloric is communicated by contact, its passage is slow and gradual, and it is supposed to be successively propagated from one layer of particles to another to the end most remote from the source of heat. It has been inferred

* The use of this term is sanctioned by Dr. Wells and Dr. Thomson.

that this effect is produced by the mutual attraction which subsists between caloric and the particles of the conducting body.

This property exists in very different degrees in different bodies; some conduct heat with great facility, while it is slowly performed by others. A piece of charcoal while red hot at one extremity may be held by the other without inconvenience; but in the same circumstances a rod of metal would be so heated as to burn the skin. If the hand be invested in woollen, no great difference of sensation will be perceived; but if it be immersed in quicksilver, that fluid will feel cold and it requires the evidence of the thermometer to convince us, that these bodies are of the same temperature. The fact is, that the impressions depend altogether upon the relative conducting powers of these substances. In reference, therefore, to this property, all bodies have been divided into good and bad conductors of caloric.

CXXIX. The conducting powers of bodies, when the forms are considered, are proportional to their densities. Solids are better conductors than any other class; and among these, the metals possess this power in the greatest degree. But this law does not apply to bodies of the same form, and the difference in this respect is such that their relative powers of conduction can be learnt only by experiment. For example, the conducting power of platinum, which is the densest of bodies, is inferior to that of zinc; and this property exists to a greater degree in tin than in lead, although the former is specifically lighter than the latter. The relations of the metals to each other in reference to this power, may be ascertained by the simple method of Ingenhouz. Wires or rods of these bodies of the same length and diameter are immersed to a certain depth in melted wax, and afterwards removed. When they are cooled, the naked extremities are plunged into hot oil, and their conducting powers are determined by the quantity of wax melted from each in a given time. By this method their conducting powers were ascertained to be in the follow-

ing order, silver, gold, copper, tin, platinum, iron, steel, lead. Subsequent experiments of other chemists have shown that of all the metals, platinum is the worst conductor. Dr. Wollaston found that when silver, copper, and platinum were exposed in this way to heat, $3\frac{1}{2}$ inches of wax were melted on the silver, $2\frac{1}{2}$ on the copper, and only 1 inch in the same space of time on the platinum. The late experiments of Sir H. Davy on flame show that this last metal is inferior to others in conducting power.

It was ascertained by Count Rumford, that the state of a body, with regard to the aggregation of its particles, has an influence upon its property of conduction. A solid mass of iron will conduct better than the same weight of metal in filings; and saw-dust is a worse conductor than the wood from which it is separated.

Meyer has made some experiments upon the conducting powers of woods. They were found to differ from each other, but the difference is not so great as that which exists among the metals.

Glass is not a very good conductor of caloric, and hence it is liable, unless when very thin, to crack and fall to pieces on exposure to heat, different portions being unequally expanded.

CXXX. The most interesting of the experiments, in a practical point of view, which have been made on the conducting powers of solids, are those of Count Rumford, in which the subjects were the articles commonly used for clothing. Their relations in this respect to each other were ascertained by the time required to cool them from 70° to 10° of Reaumur, or 167° Fah. The substances employed were raw silk, wool, cotton, linen in the form of the finest lint, eider down, the finest part of the fur of a beaver, and of a white Russian hare. Air being taken as the standard, and its conducting power having been determined by an ingenious method to be equal to 576", the seconds required to cool the other substances, or in other words, their relative conducting powers were as follows; raw silk 1284", wool 1118", cotton 1046", lint 1296",

eider down 1305'', fur of the beaver 1296'', hare's fur 1315''.* From these results it appears, that of the seven articles employed, eider down and the fur of the hare were the worst, and cotton and fine lint the best conductors of caloric. Experiments were also made on other substances, and the conducting power of air, as before, being 576, charcoal cooled the same number of degrees, viz. 167° Fah. in 976'', lamp-black in 1171'', and wood ashes in 927''. It was found by Count Rumford that by increasing the density of these bodies, their powers of conducting were proportionally augmented; and he concluded that their imperfectly conducting powers, in their ordinary state, were to be ascribed to the air with which their interstices were filled; believing that this air was retained in the pores by a strong mutual attraction between their particles.

CXXXI. Liquids conduct caloric much more slowly than solids. When the lower surface of a glass vessel containing a liquid is exposed to heat, a current will be seen ascending in the centre, and another descending by the sides. If the heat be applied to the sides, the motions will be inverted. Hence it was supposed, that this class of bodies acquired heat in two ways, first, by their conducting power, and secondly, by their motions. Count Rumford, who turned his attention to this subject, executed a number of ingenious experiments, and from their results denied that liquids are conductors of caloric. He affirmed that, "although the particles of any fluid individually can receive heat from other bodies, or communicate it to them, yet among these particles themselves, all interchange and communication of heat is absolutely impossible."† These experiments were soon followed by those of Hope, Thomson, Nicholson, Dalton, and Murray. The sources of error in Rumford's experiments were pointed out, and more accurate methods were employed, and the fact was finally demonstrated by Dr. Murray, that liquids are conductors of caloric.‡ But they possess this power comparatively in a

* Essays, vol. ii. p. 436. Amer. ed.

† Essays i. and vi.

‡ Nicholson's Journal, vol. i. p. 241. 8vo.

slight degree, as is sufficiently proved by the experiments above mentioned; and by the fact that ice will melt in $\frac{1}{80}$ of the time at the surface, which is required for its liquefaction at the bottom of a mass of hot water. It may be shown also by an experiment of Sir H. Davy's; an air thermometer is fastened into a glass funnel, and water is poured into the vessel until it rises above the bulb; when ether is added to the water and inflamed, the coloured fluid in the stem of the instrument is seen to descend with extreme slowness.*

CXXXII. The relative conducting powers of the different airs have not been examined with much precision. Rumford infers that they obey the same laws as those which govern liquids; but M. Berthollet has advanced an opinion directly opposed to this conclusion. He remarks that the elastic fluids, instead of being bad conductors of caloric, possess this property in a high degree, although they may probably differ in this respect from each other; and he founds his opinion upon the phænomena displayed by the air thermometer, and upon the sudden dilatation observed by æronauts to happen in balloons, on exposure to the solar rays.† Mr. Leslie states from experiment that the conducting power of carbonic acid is inferior to that of hydrogen; and that hydrogen, in this respect, is superior to atmospheric air, in the ratio of 4:1. From the experiments of Mr. Dalton, the relative conducting powers of different airs are according to the subjoined table.‡

Carbonic acid	-	-	-	-	112
Sulphuretted hydrogen	}	-	-	-	100
Nitrous oxide					
Olefiant gas					
Atmospheric air	}	-	-	-	100
Azotic gas					
Nitrous gas	-	-	-	-	90
Coal gas	-	-	-	-	70
Hydrogen	-	-	-	-	40

* Plate iii. fig. 5. † Chemical Statics, note xvi. p. 465.

‡ New System, part i. p. 118.

The numbers here represent the seconds of time required to cool a thermometer heated 15° or 20° above their temperature, and introduced into a phial successively filled with the airs, the conducting powers of which were to be ascertained.

CXXXIII. The rapidity with which heat is communicated to bodies appears to be influenced by their capacities. In general, those bodies are most slowly heated and cooled, the capacities of which are greatest. Thus, if equal bulks of water and of quicksilver, at the temperature of 40° , be exposed to the air at 60° , the latter will acquire the temperature of the atmosphere much sooner than the former. Mercury will also cool much faster than water. From this fact, Mr. Leslie infers, that the relative specific caloric of different bodies may be ascertained by their rates of cooling. Equal bulks of water, nitric acid, sulphuric acid, alcohol, and olive oil were successively cooled in the same vessel from 30° to 10° above the temperature of the air, and the number of seconds required by each was as follows; water 100, nitric acid 80, sulphuric acid 63, alcohol 57, oil 46. If it be required to find their capacities in equal *weights*, they may be obtained by dividing these numbers by their corresponding densities; and the results for the most part agree with those which are derived from more elaborate methods.*

CXXXIV. From the knowledge which has been acquired respecting the conducting powers of different bodies, may be explained a variety of familiar facts. The use of clothing is merely to retain the heat which is evolved by the living system. If it be of a kind which permits caloric easily to pass through its texture, it is said to be cool; if on the contrary its texture be loose and spongy, the heat is conducted off very slowly and the clothing is considered to be warm. Hence, arises the superiority of woollen over cotton and linen in protecting us from the vicissitudes of the season. Hence, also, we perceive the reason why a covering of eider down is supe-

* Inquiry &c. p. 342, and note xxxv.

prior to every other substance as a light but effectual article of clothing.

In the inhospitable regions of the north, nature has given to animals thick coverings of fur, feathers, or down, which almost completely intercept the passage of caloric from their bodies into the air, and they live with impunity in an atmosphere, the temperature of which is often below the freezing point of mercury. Care has also been taken of the vegetable system by the use of means, which at first view would seem only to hasten its destruction. In very high latitudes the snow falls early in the season, in great quantities, light, downy, and uncompressed. A considerable portion of air is retained between its flakes, by which it slowly transmits the caloric from below, and the earth is prevented from being frozen to a depth which the transient heats of summer would be unable to reach. Hence it happens, that while the trees which rise above the snow are often rent asunder with a loud explosion, the humbler plant rests securely beneath the covering provided for it by the Author of nature. Dr. Wells attributes the effect of snow in these instances, to the obstacle it affords to the passage of radiant heat from the earth, but it is most probable that both circumstances are combined to preserve the temperature of the ground.

The knowledge of the conducting powers of bodies is useful in a multitude of cases, in which it is necessary to confine or exclude caloric. The internal surfaces of furnaces are coated with a cement of sand and clay, or of clay and black lead, or even charcoal; ice-houses are so constructed as to allow of some loose and spongy substance being in contact with their sides, in order that the progress of caloric from without may be impeded; and upon the same principle, may be explained the well known fact, that ice may be preserved longer when wrapped in woollen, than when exposed to the air,

2. Radiation of Caloric.

CXXXV. When the hand is held opposite to a fire, the sensation of heat will be perceived; and the same effect will take place when it is placed below the source of caloric. Now as nothing in the last case intervenes but the air, and as this fluid, when caloric is communicated to it, expands and rises, the impression cannot be owing to the transmission of the hot air to the hand; but rather to the action of the particles of caloric which are supposed to be thrown off from the hot body in all directions. Bodies capable of discharging caloric in this way are called radiating, and the principle, which is thus projected, radiant caloric. The facts which have been collected on this interesting subject are the results of the labours of Scheele, Pictet, Saussure, Prevost, Leslie, Rumford, Herschell, and Wells; but some of the phænomena were known to Zahn, Mariotte, the Florentine Academicians, Lambert, and Gaertner.

CXXXVI. The properties of radiant caloric, and its relations to the substance or surfaces of bodies may be demonstrated by the apparatus of Pictet or of Leslie. The former consists of two concave reflectors of tinned iron highly planished, supported in a vertical position by a wooden frame. They are placed opposite to each other, but at the distance of several feet; the bulb of a delicate thermometer is suspended in the focus of one reflector, the temperature of which is found instantly to rise when a hot body is stationed at the focus of the other.* Mr. Leslie's apparatus is composed of one reflector of planished tin, and of a parabolic figure, of the differential thermometer, and of a series of planished tin canisters from 3 to 10 inches in diameter. The canister is filled with the hot body, water for example, and placed vertically at the distance of 2 or 3 feet from the reflector, the centres corresponding with each other. One of the bulbs of the thermometer is then stationed in the focus.

* Plate iv. fig. 2.

CXXXVII. Radiant Caloric is invisible. It passes through the air apparently without retardation, without affecting its temperature, and without being affected by the mechanical agitation of the medium through which it is radiated. Its velocity, according to Pictet, is immeasurable. It passes in diverging rays from every point of the surface of the heated body, and may, therefore, be reflected downward as well as upward or horizontally. If the two metallic mirrors be suspended immediately over each other, with a space between them of 2 or 3 feet; and if the bulb of a thermometer be placed in the focus of the lower, it will rise when a hot body is stationed in the focus of the upper reflector. With his apparatus, Mr. Leslie found that the force or calorific effect was greatest in a line perpendicular to the surface of the radiating body, or equivalent to its orthographic projection; in other words proportional to the visual magnitude of the heated body, as viewed from the reflector.* Hence, the impression upon the thermometer by the heated canister is proportional to the angle it subtends, and the effect does not considerably vary, whether larger or smaller canisters be employed, provided they be placed at corresponding distances from the reflector. Thus a 3 inch canister at 3 feet distance, raised the temperature of the thermometer 50° ; one of 4 inches at 4 feet distance, 54° ; of 6 inches at 6 feet distance, 57° ; and one of 10 inches at 10 feet, 59° . It appears also, by Mr. Leslie's experiments, that radiant caloric aberrates from its course more than light.

CXXXVIII. Bodies of different natures possess the power of radiating caloric in very different degrees, and the property appears to be dependent entirely upon the nature of the surface. Mr. Leslie coated one side of a canister with lamp-black, covered a second with writing paper, applied to a third a pane of glass, and left the fourth bright and polished. When the metallic surface was presented to the reflector, the impression upon the thermometer amounted to 12° ; from the glass sur-

* Inquiry, p. 69.

face it was equal to 90° ; from the papered side 98° ; and 100° from the lamp-black. The canister having been filled with hot water, it is obvious that the temperature of all the sides must have been the same, and the difference of impression, therefore, on the thermometer could have been owing only to the different powers of radiating caloric possessed by the bodies with which they were coated. Of all the substances which were examined by Mr. Leslie, lamp-black exhibited this property in the greatest degree. The impression upon the thermometer by this substance being estimated at 100° , the radiating powers of other bodies were found to be in the following order; water by estimation 100° , writing paper 98° , rosin 96° , sealing wax 95° , crown glass 90° , China ink 88° , ice 85° , isinglass 80° , plumbago 75° , lead 19° , polished iron 15° , tin-plate, gold, silver, and copper each 12° . By scratching or generally furrowing their surfaces, the metals were found to radiate a larger amount of caloric; in the case of tin, the impression increasing from 12° to 22° ; but if the furrows were made irregularly or in opposite directions it was again reduced. The metals, then, when their surfaces are polished, possess the lowest radiating powers, for from these experiments, it appears that at the same temperature, lamp-black radiates more than eight times the quantity of caloric which is radiated by tin.

CXXXIX. The powers of bodies to radiate and to absorb caloric are proportional to each other. Those which absorb with the most ease, also radiate with the greatest facility. If in the usual arrangement, the bulb of the thermometer be coated with tin-foil, or even with gold leaf, the impression of the radiant caloric will be exceedingly slight; if the bulb be naked, the effect will be much greater, but if it be coated with lamp-black, the action on the instrument will reach its maximum. Now we have learnt from previous experiments, that lamp-black absorbs more than glass, and glass more than the metals, which is precisely the order of their radiating powers.

CXL. But the radiating and reflecting powers are inversely proportional to each other. Those bodies which reflect the

most, radiate the least, and those which radiate the most, reflect the least caloric. Metals reflect caloric with the greatest facility; if a glass mirror be substituted for the tin reflector, the positions of the hot body and the thermometer being the same, the effect will be considerably diminished, and if the surface of the glass be coated with lamp-black, no action upon the thermometer will be perceived. But if the last coating be removed and the glass be covered with a film of gold-leaf, the impression upon the instrument will be equal to that which was produced by the metallic mirror. Hence it appears, that glass reflects less caloric than metals, and that the reflecting power of lamp-black is inferior to that of glass; on the other hand, glass radiates more caloric than the metals, and lamp-black more than glass. If the surface of the metallic mirror be furrowed or roughened, or if it be covered with a thin film of amalgam, its power to reflect caloric will be diminished, while the power to radiate will be proportionally increased. The metallic bodies possess this property in different degrees, and it will be seen by the following table of Mr. Leslie, that those which reflect the most radiate the least, and that the converse of the proposition is equally true. To this table have been added the radiating powers from the same author.

Substance.	Reflecting power.				Radiating power.			
Brass	-	-	-	100				
Silver	-	-	-	90	-	-	-	12
Tin-foil	-	-	-	85				
Block-tin	-	-	-	80	-	-	-	12
Steel	-	-	-	70	-	polished iron	-	15
Lead	-	-	-	60	-	-	-	19
Tin-foil softened by merc.				10				
Glass	-	-	-	10	-	-	-	90
Glass coated with wax				5	-	scaling wax		95

It appears also from these experiments that, as might be expected, the reflecting and absorbing powers of bodies are in the inverse ratio to each other.

CXLI. Radiant caloric may be arrested in its progress either indefinitely or for a limited time by solid bodies. Caloric is often associated with light, and they may be separated for a time by interposing in the line of the radiant heat a pane of glass. The rays of light pass through the vitreous screen with little diminution of intensity, while those of caloric will be arrested. The effect of screens depends upon their natures, their thickness, and the distance at which they are placed from the radiant point. If the interposed body be metallic with a smooth surface, the effect upon the thermometer, even when a powerfully radiating body is presented, will be imperceptible. But on using a pane of glass, the impression was found by Mr. Leslie to be equal to 20° , and with writing paper to 23° of his scale. Mr. Leslie denies that radiant caloric can pass directly through glass; but the later experiments of Dr. De la Roche demonstrate this fact, as well as many others of importance in relation to this subject. He has proved, 1. That invisible radiant caloric may in some circumstances pass directly through glass. 2. That this quantity is so much greater, compared with the whole heat radiated in the same direction, as the temperature of the source of heat is more elevated. 3. That the calorific rays, which have already passed through a screen of glass, experience in passing through a second glass screen of a similar nature, a much smaller diminution of their intensity, than they did in passing through the first screen. 4. That the rays emitted by a hot body differ from each other in their faculty to pass through glass: hence it is inferred, that the calorific rays are of different kinds. 5. A thick glass, though as much or more permeable to light than a thin glass of worse quality, allows a much smaller quantity of radiant heat to pass. The difference is so much the less as the temperature of the radiating source is more elevated. 6. That the quantity of heat which a hot body yields in a given time by radiation to a cold body situated at a distance, increases, *cæteris paribus*, in a greater ratio than the excess of temperature of the first body above the

second.* The last proposition is one of the most important. The effect on the thermometer is less in proportion as the thickness of the screen is greater. With a deal board $\frac{1}{8}$ of an inch thick, the impression was equal to 20° ; when it was $\frac{3}{8}$ of an inch in thickness, it was equal to 15° ; and when 1 inch, only to 9° . With regard to distance, it was found by Mr. Leslie that when the screen of glass was 2 inches from the radiating body, the effect amounted to 20° ; in proportion as it was removed toward the reflector, the impression was diminished, and when it was 1 foot distance from the canister and 2 from the mirror, the action upon the thermometer did not exceed $\frac{1}{30}$ part of the full effect.

The influence of compound screens is varied according to their nature and the mode in which their component parts are joined. When one side each of two panes of glass was coated with tin-foil, and the coated surfaces were brought into contact, the impression received by the thermometer, when the whole was interposed as a screen, was equal to 18° ; but on being employed in the same office, after the plates had been separated and re-united with the metallic coatings outward, no perceptible effect was produced upon the temperature of the thermometer. In the first case the glass being opposed to the radiant caloric, absorbed a portion of it, which was successively transmitted through the vitreous substance and metallic coats, to the outer surface of the second plate, by which it became a radiating surface and capable of increasing the temperature of the thermometer in the focus of the reflector; while in the second case, the tin-foil being opposite, the rays of caloric as they fell upon the metallic surface were reflected, and, of course, the temperature of the screen could not be increased.

Mr. Leslie, however, gives a different explanation, and from the results of his numerous and ingenious experiments draws the conclusion, that radiant caloric is not thrown off from heated surfaces, and darted through the air to distant

* *Annals of Philosophy*, vol. ii. p. 109.

objects, but that the air itself constitutes the medium of its transmission. He supposes that the stratum of air, immediately in contact with the heated surface, acquires a portion of its high temperature, by which it is expanded and made to press upon the next stratum of particles; this in like manner recedes, and thus an undulation or chain of aërial pulsations is produced. "The mass of air without sensibly changing its place, suffers only a slight fluctuation as it successively feels the partial swell; but the heat attached to this state of dilatation is actually transported and with the swiftness of sound." This hypothesis has been most ingeniously applied to the solution of the phenomena of radiant caloric. But when examined in detail, it will be found accompanied with some material difficulties. Mr. Leslie is strongly in favour of the opinion that heat is matter;* yet he has not accounted for the transfer of caloric from one layer of particles to another. It is not to be supposed that the first stratum of heated air is propelled, nor that its particles are darted off to the thermometer, for these assumptions must involve a physical contradiction. Nor is it necessary, in order to explain the effect of screens, that his views should be adopted. The solution given by Dr. Murray† appears adequate, and it derives additional force, from the researches of Dr. De la Roche. Indeed, the experiments of the last mentioned chemist are directly opposed to those of Mr. Leslie; and they also show a much stricter analogy between light and heat, than is admitted by the author of the "Inquiry."

CXLII. The experiments of Dr. Herschel, Dr. Wollaston, Mr. Reller, and Sir H. Englefield have proved that besides the ray which produces colour, the solar beam contains calorific rays, and that the heat of the sun is derived from the presence of radiant caloric. When light is decomposed by the prism, it is found that each ray of the spectrum produces heat, but not in the same degree; supposing the calorific effect

* Inquiry, p. 140.

† System of Chemistry, vol. i. p. 319.

of the middle or green ray to be represented by 22.4, that of the violet at one extremity will be 16 ; and that of the red at the other extremity 55. The illuminating and heating rays, therefore, obey different laws. The greatest light exists in the middle of the coloured image, and diminishes toward each end, while the strongest heat is found in the red ray and lessens through the whole series of colours to the violet. Hence, the calorific are less refrangible than the colorific rays ; and the heating effect is in the inverse ratio of their refrangibility. These facts, which were discovered by Herschel, led him to suspect that the calorific rays might extend beyond the spectrum on the side of the red ray, and on making the trial he found that his conjecture was verified. The thermometer, when placed just without the coloured line, rose higher than when exposed to the red ray ; and in proportion as the distance was increased, the heat was augmented until the bulb was half an inch from the coloured spectrum. Here existed the maximum temperature, but the heat was still perceptible when the distance from the red ray was equal to $1\frac{1}{2}$ inch. The amount of the difference in the heating powers of the rays was afterwards determined by Sir H. Englefield. A thermometer with a blackened bulb exposed to the blue ray rose in 3 minutes 1° ; to the green ray 4° ; to the yellow 6° ; to the full red ray in $2\frac{1}{2}$ minutes 16° ; on the confines of the red ray $15^{\circ}\frac{1}{2}$; and beyond the visible light 18° .

M. Berard executed some experiments in 1813, and by the use of the Heliostat, an instrument by which the rays of light may be fixed for a considerable time in one position, he was able to obtain very accurate results. He thus confirmed the discovery of Herschel, but he found, contrary to the experiments of that philosopher, that the greatest heat existed at the extremity of the spectrum, but not beyond the red ray. He also proved that the radiant heat of the sun is like light susceptible of polarization. The absolute intensity of the heat produced was likewise less in the experiments of Berard than in those of Herschel.*

* Annals of Philosophy, vol. ii. p. 151.

The radiant caloric of the sun possesses the same properties as those which belong to terrestrial caloric. It passes through the air without retardation and without communicating temperature to its particles; it is arrested by opaque and transmitted by diaphanous bodies, and is susceptible of refraction and reflection. The only difference between them exists in the greater facility with which solar heat traverses solid, transparent media. Dr. Herschel found that of 1000 rays of the sun which were made to impinge upon a piece of glass surrounding the bulb of a thermometer, 750 were transmitted, and 250 arrested; of 1000 rays emanating from a burning candle and made to fall upon the same instrument, 375 only were transmitted, while 625 were stopped. By previously separating the calorific from the colorific rays by the prism, the experiment was performed in a more unexceptionable manner. Of 1000 solar rays only 71 were arrested, but when the thermometer was exposed to the radiant caloric of a common stove, 300 only were transmitted. The rays of the sun, it is well known, when brought to a focus by a convex lens, produce an intense heat, but the radiant caloric of a fire cannot be so concentrated as to cause any obvious rise of temperature.

CXLIII. The relation existing between the radiating and conducting powers of bodies, if known, might perhaps afford some useful practical hints. Dr. Murray considers them as inversely proportional to each other, whence it would follow, that bodies which are good conductors should, when heated, lose more of their caloric by slow communication than by radiation, while the bad conductors should cool principally by the radiation of their heat. Mr. Leslie has made some experiments to determine this point, and he concludes that at low temperatures, the portion of heat *conducted* off by the air from a blackened surface is somewhat less, and at high temperatures considerably greater than what is spent by radiation.

CXLIV. Two hypotheses have been formed to account for the phenomena of the radiation of caloric. Pictet supposed

that when the temperature of bodies is uniform, a state which has been called the tension of equilibrium in the caloric is produced, and it is at rest. But when another body, either warmer or colder is introduced, this tension is for a time destroyed; in the first case radiant caloric passing from, and in the other flowing toward the new body, until the equilibrium of temperature again takes place. In the hypothesis of Mr. Prevost of Geneva, caloric is considered as a discrete fluid which is radiated at all temperatures and in all directions from bodies; when the temperature is the same, a ray passing from one takes the place of a ray emanating from another, and the relative proportion remains the same; but as the amount radiated is proportional to the temperature, a hot body radiates more than one which is cold, and it is this excess only which produces the phenomena of radiant heat; the time increasing in an arithmetical ratio, and the excess diminishing in geometrical ratio. The hypothesis of Mr. Prevost seems to have been generally adopted.

CXLV. A curious experiment, which affected the theory of the materiality of heat, or at least favoured the idea of the existence of frigorific matter, was first performed by the Florentine Academicians, and repeated by subsequent chemists. It is the apparent radiation of cold. If a mass of ice, or a vessel containing a freezing mixture be substituted for the hot body at the radiant point, the temperature of the thermometer placed in the focus of the reflector will be reduced. This experiment gives the best results when it is performed in a room, in which the temperature is uniform and some degrees above the freezing point, and when the air is perfectly calm. The instrument employed should be an air thermometer with its bulb blackened. The phenomenon is explained on the principles of radiant caloric, by supposing that when the cold body is introduced into the arrangement, those bodies which are of a superior temperature immediately begin to radiate their excess of caloric towards it, the thermometer radiates both to the ice and the reflector, and, in consequence of losing a

portion of its caloric, its temperature is proportionally diminished. Count Rumford believed in the actual existence of frigorific particles, and executed some ingenious experiments to support his opinion.

CXLVI. The principles which have been deduced from the investigations made into the phænomena of radiant caloric, may be successfully applied to the solution of many interesting facts. Of these none has been more completely developed, than the formation or deposition of *dew*. Until within a very short time, this deposit had been supposed to depend entirely upon the reduction of temperature in the air during the night, and the consequent separation and precipitation of its moisture to the earth. But it has been amply demonstrated in the admirable work of Dr. Wells, that the cause may be found in the radiation of caloric from the ground.* He has proved by experiment that dew appears in greatest quantity upon those substances which radiate the most caloric ; that the temperature of such substances, e. g. grass, is several degrees lower than that of the air above, or of the ground below it ; that the radiation is greatest and the dew most copious in calm and serene nights ; that the process is diminished or suspended by high winds, and by the presence of clouds, and that in those cases the temperature of the grass, &c. is the same as that of the air. From such facts as these, and a multitude of others which are stated by Dr. Wells, the conclusion may be drawn, that on the decline of the sun in serene weather the ground and the vegetables upon its surface begin to radiate caloric into space, that, in consequence, their temperature falls, the air coming into contact with them has its capacity of retaining moisture diminished, and a proportional quantity is deposited in the form of dew. If the wind be high, successive portions of comparatively warm air are applied, heat is rapidly communicated, and uniformity of temperature is produced. Hence, in these circumstances, no dew will be depos-

* An Essay on Dew ; and several appearances connected with it. By William Charles Wells, M. D. F. R. S.

ited. It is thought by Dr. Wells that the chill which is experienced on exposure to night air when the sky is clear, may be owing to the rapid radiation of caloric from the body. The effect is more sensible in the country than in town, and he has proved that the process of radiation is greater in the former than in the latter situation. The use of snow and artificial coverings in protecting plants is ascribed to their influence in diminishing radiation; but something ought to be attributed to their imperfectly conducting powers. This theory has also been ingeniously applied to the explanation of what, in this country and the West Indies, is believed to be fact, that the beams of the moon promote the putrefactive process in animal substances. These bodies are hung in the open air, and as the nights are generally calm and serene, radiation of caloric takes place, they become comparatively cool, dew is deposited and in warm climates moisture hastens putrefaction. The process of making ice practised in the south of Asia which has been ascribed by Dr. Black and other chemists, to evaporation, most probably depends upon the loss of heat by radiation. It is prepared in Bengal. Broad, shallow trenches are dug in the ground, and are then nearly filled with straw; upon this are placed rows of shallow pans partly filled with water at a time when the air is clear and several degrees above the freezing point of water. During the night ice is formed, which is collected and deposited in woollen bags early the next morning. The formation of this ice was attributed to the rapid evaporation of a portion of water and the diminution of temperature in that which remained. Dr. Wells performed this experiment and succeeded; and after having attentively considered all the circumstances with which it was connected, he concluded that the production of ice was owing to the loss of heat, not by evaporation, but by radiation of caloric from the surfaces upon which the vessels were placed. There is no doubt that some of the effects should also be attributed to the radiation from the water itself, as its power in this respect is equal to that of lamp-black.

CXLVII. Tubes intended to heat apartments by warm air or steam should vary according as it is wished to convey or communicate caloric. In the first case they should be metallic with polished surfaces, and in the second, rough and blackened by paint or black-lead. Silver and planished tin vessels are found to be better adapted to preserve the heat of liquids, than those of porcelain or stone-ware, as they radiate less heat and are longer in cooling. Culinary vessels likewise answer their purposes best, when the surfaces exposed to heat are blackened by the smoke of burning fuel, which covers them with a coating highly receptive of caloric.

One of the most useful improvements which have been made in consequence of the knowledge of the laws of radiant caloric is that of Count Rumford, in the construction of fire-places. He has proved that the warmth of fires is owing principally to the radiation of heat. But previous to his time, the form, at least in this country, was extremely unfavourable to the passage of the caloric into the room. The fire-place was deep, its mouth was wide, and the sides were nearly parallel with each other. The consequences were, that radiation was effectual only from the front, and that the air which had been warmed by previous contact with surfaces in the room escaped through the chimney. To obviate these inconveniences, the mouth of the fire-place was narrowed, its depth was diminished, the back was inclined forward, and the sides were made to diverge from each other at a very large angle. Two essential advantages were thus gained. The radiation of caloric from the fire became effectual from the sides as well as the front of the fire, and a considerable proportion of heated air remained in the apartment. Experience has amply demonstrated the utility of this mode of construction. The sides may be formed of such substances as are known to reflect caloric, for from their disposition, the reflected rays would pass into the room; or they may be such as powerfully absorb and radiate caloric.

The colour of our clothes probably has some effect in preserving or diminishing the temperature of the body. Black garments must be warmer in the sun and cooler in the shade, than those of any other colour. White clothes are cooler in the sun and warmer in the shade than those which are black. In polar regions the furs of most of the animals become white in the winter; they therefore radiate less caloric and the continued influence of their imperfectly conducting and radiating powers, preserves the temperature of their bodies uniformly the same during the long period of intense cold, to which they must be exposed.

SECTION V.

Sources of Caloric.

The sources and the means of producing Caloric may be reduced to six, viz. the sun, electricity, combustion, friction, percussion, and mixture.

CXLVIII. *The sun.* This luminary, the diameter of which is estimated at 883,246 miles, and its solid contents at 333,928 times that of the earth, is the great source of terrestrial heat. Hence, upon the supposition that caloric is matter, the quantity received by the planets must be immensely great, and this fact has furnished an argument against the materiality of this principle; for it seems incredible that the bulk of the sun should not have been lessened, from the radiation of so much of its matter, and for so many centuries, to the different parts of the solar system. To do away the force of this objection, Mr. Leslie has attempted to show, that upon the supposition that the sun is a solid globe of caloric, and that the heat absorbed each hour by the earth be reduced to the density of water, it would form a film amounting to no more than $\frac{1}{300,000,000,000}$ part of a foot in thickness.—“Wherefore by the continued discharge of light (or caloric) the sun will suffer a waste from his surface, of the depth of one foot

only in the space of 700 years.** This philosopher has also inferred that the mean temperature of the earth increases at the rate of 1° in a series of 2405 years.† But it has been demonstrated that in the absence of the sun, the earth radiates into space a great quantity of caloric. The destination of this caloric is unknown; but it is possible that by this process, the equilibrium in the reception and the emission of caloric by our globe at least, is preserved. It is very doubtful whether the sun is to be considered as a mass of solid igneous, and luminous matter. The observations of Herschel seem to have rendered the opinion plausible, that the mass of this luminary is opaque, and that its heating and illuminating powers reside in an atmosphere, through the occasional openings of which, usually called spots, the dense and probably inhabited surface of that wonderful globe is visible.‡

CXLIX. The extremes of natural temperature hitherto observed are not far removed from each other. In tropical climates, the thermometer has been known to rise to 115° in the shade; and in high northern latitudes to descend to -56° . The greatest range, therefore, may be estimated at 170° . In Massachusetts, including Maine, the difference amounts to about 120° . The mean temperature of the earth is thought to be about 50° . The heat produced on the thermometer by the direct impression of the solar rays does not often exceed 128° ; but by surrounding the instrument with such substances as absorb caloric rapidly and conduct it slowly, a much greater effect may be perceived. Saussure introduced a thermometer into a box, three sides of which were charred, while the fourth was formed of glass; on exposing it to the sun in summer, it rose from 75° to 221° . Professor Robison repeated this experiment, and, by increasing the quantity of non-conducting substance, he succeeded in one instance in causing the thermometer to rise to 237° ; and in several experiments to 235° . The increase of heat depends upon the kind of surface upon which the solar rays impinge. Dr. Franklin placed

* Inquiry, p. 179. † Ibid, p. 181.

‡ Phil. Trans. 1801, p. 265.

upon the snow in fair weather, four equal pieces of cloth, white, red, blue, and black ; and he found that the black sunk furthest, and the white least into the substance of the snow. Sir H. Davy exposed to the action of the sun six equal pieces of copper, respectively coloured white, yellow, red, green, blue, and black ; to the under side of each was attached a piece of cerate which melted at the temperature of 70° . The cerate was melted from them in the following order, black, blue, green, red, yellow, white. The results of these experiments agree with those which have been noticed on the radiation of heat. The bodies most easily heated were those which are known to radiate most caloric ; it appears, however, that when such bodies are exposed to heat, the absorbing is superior to the radiating power.

CL. By concentrating the solar rays, very high degrees of heat may be obtained. As the radiant caloric of the sun, like its light, is susceptible of refraction and reflection, this concentration may be produced by lenses and specula. The lens may be formed of a solid, transparent body, or of two glasses in the shape of menisci, the space between them being filled with some transparent liquid. In one of the comedies of Aristophanes, Strepsiades makes use of a crystal globe filled with water to burn the documents of his debts. The largest lenses ever constructed are those of Tschirnhausen and of Parker. The former is 33 inches in diameter, its focus is $1\frac{1}{2}$ inch and formed at the distance of 12 feet from the lens. The latter is $32\frac{1}{2}$ inches in diameter, its focus is 1 inch and formed 6 feet distant from the lens ; it weighs 212 pounds. In consequence of the large diameter of the focus, a smaller lens is commonly employed to condense the rays into a still smaller space. Ice may be employed for this purpose, and it is stated by Mr. Scoresby, that in his voyages to Greenland, he amused himself in making lenses of *fresh water* ice, with which he was able to enflame gun-powder, to light the pipes of the sailors, and even to melt lead.* The speculum is formed of com-

* Annals of Philosophy, for Aug. 1815.

pounds of the metals which are very hard and are susceptible of a fine polish, in order that the rays of the sun which strike upon their surfaces may be reflected. They are concave, and the rays thus thrown off are brought to a focus. The speculum of M. M. Viletti is 43 inches in diameter, the focus is $\frac{1}{2}$ inch and formed 3 feet from the reflector. Its weight is 400 pounds. Intense degrees of heat are produced in the foci of these instruments. The speculum, however, is more powerful than the lens; it collects the rays more perfectly, the focus is nearer and smaller, and the rays are more condensed; but it is less convenient because the rays are necessarily directed upward. It has been recorded that Archimedes set fire to the Roman fleet before the walls of Syracuse; and that Proclus burnt the ships of Vitellianus at Constantinople, by means of the rays of the sun concentrated by specula. These facts were considered by many as ingenious fable, until the practicability of communicating fire in this way was demonstrated by the celebrated experiment of Buffon. By a simple method he arranged a number of small specula in such a way as that the rays reflected from them might be concentrated upon a single point. With 40 of these he set fire to wood at the distance of 66 feet; with 45 he melted tin at 20 feet, and with 117 he melted silver; when the number amounted to 168, wood was kindled at 200 feet, tin melted at 150, lead at 130, and silver at 60 feet.

The lens of small diameter is often employed by the chemist to inflame substances in close vessels in delicate synthetical or analytical experiments.

CLII. Electricity. When the most perfect conductors of electricity are powerfully excited, they become red hot, and are sometimes melted. It is frequently the case that the metallic bodies about the persons of those who have been destroyed by a stroke of lightning are found to have been partially or totally melted. The metals may be fused by subjecting them to the influence of a charged electrical battery; but more decisive effects of this kind are produced by voltaic electrici-

ty. The battery of 2000 double plates at the Royal Institution, and the great arrangement of Mr. Children excite a temperature which has never probably been exceeded, the most fixed and infusible substances in nature being instantly melted or converted into vapour.

CLII. *Combustion.* The caloric produced in this process has been supposed to be evolved in consequence of the union of one or all of the constituents of the combustible body with oxygen, the capacity of the product being less than the mean capacities of the two separately taken. Ordinary combustion is dependent upon the presence of atmospheric oxygen, and the temperature excited has been inferred to be proportional to the amount of the oxygen combined in a given time. The caloric which is present more probably results from the exertion of powerful affinities, and the intensity of the combinations. Many of the operations of the chemist, which require a moderate heat, are performed with lamps. The liquids employed are oil and spirit of wine. The latter burns with a light, lambent flame, and produces nothing which can soil the apparatus; the former affords a greater heat, but in the common lamp evolves a thick, disagreeable smoke. This inconvenience is removed in Argand's lamp, the oil being more completely consumed, and the heat being rendered more intense by the strong current of air which passes through the chimney. When a second circular wick is added, as in the lamp of Mr. Webster, it is capable of producing a degree of temperature sufficiently high to complete a great variety of experiments.

In those operations in which a still higher heat is required, it is necessary to make use of wood, charcoal, or pit-coal, and to consume them in furnaces. The furnace, which is varied in form and size according to the uses to which it is to be applied, consists essentially of the ash-pit, the body, and the chimney. The temperature produced in it depends upon the quantity of air applied in a given time, and upon the proportion between the body and length, and diameter of the

chimney. These proportions have not been very accurately ascertained. The air-furnace requires the strongest draught, and it may generally be obtained by placing it in the middle of a column of air from 40 to 50 feet in length, the air being conducted to it by a flue open to the atmosphere. The portable Universal furnace of Mr. Accum will be found very useful in a great variety of chemical operations. The *blast* furnace is intended to produce an intense, but circumscribed heat, and the air is conveyed to the fuel by the blacksmith's bellows; but the organ-bellows has been found equally effectual and much more convenient, as it may be placed immediately beneath the forge. Portable table-furnaces are also employed, and a variety of these, as well as common furnaces, may be found described by Mr. Aikin,* Dr. Henry,† and M. Thenard.‡

The combustion of charcoal produces a strong heat, and it leaves little residuum; but it burns rapidly and requires frequent renewal. Wood is an inconvenient fuel; the vapour formed reduces the temperature, much soot is carried into the chimney, and it is difficult to regulate the heat. It is most useful in the sand-bath furnace. Pit-coal is also capable of producing a high heat; but the bitumen it contains distils over in the form of tar, and a light charcoal rises, which is apt to choak the chimney and diminish the draught. It should therefore be used in the form of coak, which is to coal what charcoal is to wood. A mixture of coak and charcoal is the fuel best calculated to excite an intense and continued heat. That species of coal which is destitute of bitumen and which is known among us by the name of Rhode-Island coal, the anthracite of mineralogists, occasions by its combustion a temperature as high as that of the mixture just mentioned, but it is difficult to manage.

CLIII. The blow-pipe is a valuable appendage to the laboratory, and, including its modifications, it is capable of exciting all degrees of temperature. The common blow-pipe

* Chemical Dictionary, article Furnace.

† Elements of Chemistry. ‡ *Traité de Chimie*, t. iv.

consists of a metallic tube, with an ivory mouth-piece at one end, a very small opening at the other, and a bulb in the middle to condense the aqueous vapour of the breath. When it is to be used, the wick of a candle is bent horizontally, the air is blown through it rather from the mouth than the lungs, and directed upon the flame so as to cause it to assume the form of a cone. The greatest heat exists at the apex of the inner or blue flame. By certain arrangements, a still higher temperature may be obtained. These are, 1. By directing a stream of oxygen gas upon burning charcoal. 2. By exposing substances to the flame of a spirit-lamp set in motion by oxygen gas, as discovered by Dr. Marcet. 3. By a kindled stream of oxygen and hydrogen gases pressed out respectively from separate reservoirs, as in the blow-pipe of Dr. Hare of Philadelphia. 4. By the oxy-hydrogen blow-pipe of Dr. Clarke, in which the airs are previously mixed and crowded into a reservoir, from which they issue with force by their own elasticity, when a communication through a very small tube is opened to the atmosphere.

CLIV. *Friction.* The temperature of bodies may be raised by friction. The Aborigines of America, and of the neighbouring islands, procured fire by rubbing together two sticks, one of hard and the other of soft wood. The parts of machines which are in contact, and which are exposed to rapid motion, excite considerable heat, and wheels of carriages have been known to take fire from the friction on the axle. In the boring of cannon, Count Rumford ascertained that much heat was evolved, and by enclosing a brazen cylinder in a box containing water and subjecting it to this kind of friction, the liquid was made to boil. In a similar experiment, the metallic chips which were separated amounted in weight only to $\frac{1}{948}$ part of that of the cylinder, and yet the quantity of heat produced was found equal to 66,360°. The caloric thus evolved could not have been the consequence of a diminution of capacity, for the shavings had the same capacity as before; nor was it the result of combustion, for when the ap-

paratus was under water, the atmospheric air was excluded and the substance of the cylinder had not suffered the change in properties which arises from its combination with oxygen. The great increase of temperature therefore cannot be explained upon the supposition of the materiality of caloric unless we believe with Dr. Murray, that by a temporary compression the capacity was diminished, and that when the compressing force was removed, and the capacity was restored, caloric was derived from the substance of the cylinder and from the earth with which the apparatus was in connexion.* But it is difficult to conceive how it should happen that when the substance of the cylinder nearest the points of friction became heated from a partial diminution of capacity, that some caloric should not again be absorbed when the capacity was restored. This mode of explanation gives to caloric and electricity an analogy in properties, stricter than experiment and observation will warrant; and it must be concluded either that in the present state of our knowledge, the production of caloric by friction is inexplicable, or that it is the consequence of increase of motion among the particles of the bodies which are exposed to it.

CLV. *Percussion.* If a rod of iron be laid upon an anvil, and one end of it be repeatedly struck with a hammer, it will soon grow sufficiently warm to inflame sulphur. It may even be rendered red hot. If the specific gravity of the iron before the experiment be 7.788, it will be found after it to amount to 7.840. The condensation amounts to nearly $\frac{1}{150}$ part; and yet by this slight increase of specific gravity, a quantity of caloric which must be estimated to be equal at least to 800° is evolved. M. M. Berthollet, Pictet, and Biot, have made some accurate experiments upon this subject. They took pieces of gold, silver, and copper, of the same size and form, and subjected them successively to percussion, proper precautions having been used to preserve them at the same temperature previous to the experiment. The copper evolved the most

* System of Chemistry, vol. i. p. 435.

and the gold the least heat. The temperature in each was raised highest by the first blow. Thus, after the first, the temperature of the copper rose 17.44° ; after the second it increased 7.30° ; and after the third 1.90° ; the whole quantity being 26.64° . The specific gravity of the copper was 8.8529; after the first blow it was 8.8898, and after the second 8.9081. From these, and similar experiments, it has been concluded that the heat evolved by percussion is caused by and proportional to the condensation, and that caloric is forced out of the bodies in consequence of an approximation of their particles. If the production of caloric diminishes in iron in the same ratio with that in copper when exposed to percussion, the high temperature which may be effected in the former cannot be explained on these principles. But iron, which has once been exposed to percussion, cannot be heated in the same way a second time; it becomes so brittle as to fall to pieces under the hammer, and it regains its malleability and power of evolving caloric only by being heated red hot in the fire, and afterwards cooled. The brittleness and condensation are inferred then to depend upon the loss of part of its specific caloric by the pressure to which it had been exposed. But percussion may so alter the relative arrangement of the particles as to diminish their cohesion in different parts of a mass of iron, and thus enable them to separate by the application of a comparatively small force; and the phænomenon of heat may depend upon the motions of the particles being increased and performed in a smaller space.

The effect of sudden and great compression is to raise the temperature of bodies, and it has been said by Mr. Dalton, that when air is condensed into a space equal to half its original volume, its heat is augmented 50° . The experiments of M. Biot and Mr. Northmore demonstrated in a more positive manner the high temperatures which were occasioned by a sudden diminution in the bulk of elastic fluids; the former, by a violent compression of a mixture of oxygen and hydrogen, caused them to unite with an explosion, which terminated in

the production of water. The general fact is also proved by the effects of an instrument, which is now familiar to many, and which has been called, if I mistake not, the *pyro-pneumatic* machine. It consists of a brass tube from 8 to 12 inches in length, open at one end, but terminated at the other by a stop-cock having a small cavity. Into the tube is fitted a piston which moves freely in the bore, but which is air-tight; when it is to be used, the piston is drawn up, a piece of tinder, which has been previously soaked in a solution of nitre or nitrate of lead and thoroughly dried, is put into the cavity of the stop-cock, it is then turned, so as to be opposite the mouth of the tube, the piston is driven down with force, and the heat evolved by the compression of the air inflames the combustible body.

CLVI. *Chemical action.* In almost all cases in which affinities are intensely exercised, light and caloric are evolved. Where the action is less energetic, heat, but not light, becomes perceptible. Independently of combustion, the caloric which results from chemical affinities, is not applied to any economical purposes. The only exceptions are those which have been called fermenting mixtures, such as tanners' bark, and the refuse of the stable. When large quantities are employed, a moderate and uniform temperature is produced, which has been successfully applied to the formation of some of the pigments used in commerce.



CHAPTER III,

OF LIGHT.

CLVII. The great source of light is the sun ; but this principle is also transmitted to us from the celestial bodies, and it is evolved or produced by the mutual action of the different species of matter, which constitute our globe. It can hardly be doubted, that matter which is radiant exists between us and the sun ; for the phænomena of shadows and the aberration of light from the fixed stars prove both that the cause moves in a rectilineal direction, and that its motion through space is performed in time ; but it has not yet been demonstrated, that these appearances are dependent upon the presence of a specific and imponderable luminous fluid. Some notice will be taken of the theories of Light in a future chapter, but it may be observed, that whatever may be the real nature of this matter, its particles must be inconceivably minute, and endowed with mutual and high repulsive energies.

CLVIII. It was discovered by Roemer, and confirmed by Bradley, from the eclipses of one of Jupiter's satellites, and from the aberration of light, that its particles move at the rate of at least 164,000 miles in a second of time, and that a ray of light, therefore, projected from the sun, occupies about $8\frac{1}{4}$ minutes in travelling across a semi-diameter of the earth's orbit, or a space equal to 80,000,000 of miles. It has been calculated, that light, from its departure from the nearest of the fixed stars, which is at least 400,000 times more remote from us than the sun, is near six years in reaching our eyes, so that if one of these orbs should be suddenly annihilated, its light would be seen from our earth for nearly six years after its extinction. How grand and sublime, says the eloquent Fourcroy, are the meditations suggested by this fact, upon the immensity of space, the boundless extent of the universe, the vast number of globes by which it is traversed, and the duration of time which they measure in their silent course !

Notwithstanding this prodigious velocity of the rays of light, their momentum is inappreciable, and hence it may be proved that their particles are minute beyond comprehension, for, were they equal in weight only to the $\frac{1}{10000}$ part of a grain, the force, which they must necessarily acquire in moving through so vast a space, would be superior to that of a ball discharged from a musket with a velocity equal to 1700 feet in a second of time, and sufficient to reduce to powder every obstacle upon which they impinged. But the impulse of this matter is imperceptible. The rays of the full moon, brought to a focus by the most powerful burning glasses, and directed upon the eye, produce no extraordinary change in the sensation of that susceptible organ. It has been calculated by Horseley, that the momentum of light is equal to that of a ball of iron $\frac{1}{4}$ of an inch in diameter, moving at the rate of less than one inch in many millions of millions of Egyptian years! Such therefore must be the minuteness of its particles, that if, according to M. Biot, they were placed in a row so as to form a line one inch in length, and a person at the creation had commenced counting them, at the rate of 120 in a minute, he would have enumerated at the present time a sufficient number to have constituted $\frac{1}{3000000000}$ part of the inch!

CLIX. Bodies, which intercept the rays of light, are called opaque, and those which allow them to pass, transparent.

The space through which light travels is designated by the term *medium*.

Light, when impelled upon certain surfaces, is thrown back towards its source, or reflected. It is therefore elastic, and its elasticity is perfect, for the angle formed with a perpendicular to the surface, by the reflected ray, is equal to that, which is made by the incident ray; or in other words, the angle of reflection is equal to the angle of incidence.

In its passage through the air, light may be turned out of its rectilineal course by the contiguity of other matter, and it is then said to be *inflected* or *diffracted*. The effect is inferred to be produced by the mutual and successive attractions and repulsions existing between their particles.

A ray of light in passing from a rare into a denser medium, as from air into water, is turned *towards* the perpendicular; in passing from a dense into a rarer medium, as from water into air, it is bent *from* the perpendicular. In these cases it is said to be refracted and the property by which this effect takes place is called Refrangibility. Newton discovered that transparent inflammable bodies refract in a greater ratio than their densities, and hence was led to the sagacious conjecture that the diamond and water contain or are composed of combustible elements. In the same medium the sines of the angles of incidence and refraction always bear the same ratio to each other. From the experiments of M. M. Arago and Petit it appears that, contrary to the opinion of Newton, the refractive power of the same body in different forms diminishes in a greater ratio than its density.

CLX. If a transparent rhomboid of calcareous spar, commonly called Island or Iceland crystal, be placed over a mark traced upon a white surface, the ray, which passes through it from below, will be divided into two, and the mark will appear double. One of the pencils then, into which the ray from the trace has been separated, will have suffered ordinary and the other extraordinary refraction; or the former will have passed in the direction of the incident ray, while the latter forms with it an angle of $6^{\circ}, 16'$. This property in a crystal has been called Double Refraction, and it is exhibited by all transparent crystallized bodies, the primitive form of which is neither the cube, nor the regular octoedron. If a second rhomboid be placed over the first, in a similar position, the pencils as they come from the first crystal will be refracted, the ordinary in the extraordinary way and conversely, and only two images will appear. But if the second rhomboid be turned upon its axis $\frac{1}{8}$ of a revolution, the first remaining the same, each of the two pencils will be divided into two, and four images will be produced. When the revolution is equal to $\frac{1}{4}$, the pencil refracted in the ordinary way by the first crystal, will be refracted in the extraordi-

nary way by the second, and the one refracted in the extraordinary way by the former will be refracted in the ordinary manner by the latter, so that the number of lines which appear will be again reduced to two. At the end of $\frac{3}{8}$, $\frac{5}{8}$ and $\frac{7}{8}$ of a revolution, the same phenomenon will be observed as after $\frac{1}{8}$ of a revolution; but when $\frac{4}{8}$ and $\frac{6}{8}$ have been completed, then four pencils will be discovered like those exhibited when the crystal has been revolved $\frac{1}{4}$ upon its axis. From the facts just stated it may be concluded that the light, which forms these images, suffers some modification of properties, or some change in the arrangement of its particles, by which it is prevented from passing through the second rhomboid when its crystallized laminae are opposed to it in certain directions. Huygens explained double refraction upon the principles of his beautiful hypothesis of spheroidal undulations. Newton, on the contrary, considered the phænomena as favourable to the opinion that light consists of minute bodies or particles, and that they are endowed with powers, which might be illustrated by those of the magnet; that is to say, two sides of a particle of light exhibit powers which do not appear to be exercised by the two other sides, and that this disposition, though not identical with, yet answers to the two poles of a magnet.*

CLXI. The developement of this property of light was effected but a short time since by the discoveries of M. Malus. He found that when a ray of light was reflected from a surface of glass at an angle of $55^{\circ} 25'$, and was made to strike upon a second plate, if the planes of reflection were parallel, the light was reflected from the second, precisely as from the first surface. But if the second glass plate were turned upon its axis $\frac{1}{4}$ of a revolution, so as to render the planes of reflection perpendicular to each other, then the whole of the ray reflected from the first passed through the second, and of course there was no reflection. When the glass was turned another quarter of a circle, by which the planes were again

* Opera Omnia, t. iv. Quæst. 29.

made parallel with each other, then reflection took place from both ; at $\frac{3}{4}$ of a revolution, the light was once more transmitted by the second, and when the circle was completed, then the ray was reflected from both. What was the cause of this alternate reflection and transmission of the ray of light ? It was supposed by Malus to indicate a polarity in the particles of light, and that they were diverted from their course, or bent into another position, by certain forces acting between the particles and those of the glass ; and he therefore gave to this effect the name of *polarization*. The particles of light were supposed by him to be possessed of three rectangular axes, one of which was in the direction of the ray, and the other two produced by the influence of the repulsive forces exerted by the medium through which the ray passed, which two axes were perpendicular to the direction of these forces. Double refraction then appears to depend upon this polarization of light, and the ray which is refracted in the extraordinary manner is polarized light. The able researches of Dr. Brewster, and of M. M. Biot and Arago, have brought forward many curious and important facts connected with this subject ; but their details belong to the Mechanical philosopher.

CLXII. It was discovered by Sir Isaac Newton, that light is not homogeneous. If the solar beam be directed upon a triangular piece of transparent glass called the prism, there will be formed behind it a coloured image, usually named the spectrum, which is oblong and terminated by semi-circular arches. This spectrum exhibits seven different colours, to wit, red, orange, yellow, green, blue, indigo, and violet, of which the red is the least, and the violet the most refrangible. According to Newton, if the whole space occupied by the image be divided into 360 parts, the surface covered by each will be as follows, red 43, orange 27, yellow 48, green 60, blue 60, indigo 40, violet 80 ; but as these colours run into each other, it is difficult to define their exact limits, and the spaces have been divided differently by other philosophers. When either

of the rays is passed through a prism a second time, it suffers no change ; hence it is considered as simple or homogeneous. Of these seven colours, four may be formed by mixtures of the red, yellow, and blue, and these last, therefore, have been considered as those only to which the name of primary should be applied. Prieur, on the contrary, maintains that all the others may be produced from the red, green, and violet. It is the general opinion, however, that each of them is a distinct and independent colour.

The prismatic rays differ from each other in their illuminating powers, for it was found by Herschel that the most intense light existed in the middle of the spectrum, or green ray, and diminished toward each extremity ; hence in this property they vary from the power of producing heat ; for, as has been stated, (CXLII.) the greatest calorific effect resides in the red or least refrangible ray, and diminishes in intensity through the whole of the spectrum to the violet ray, which is the most refrangible.

The properties of light, which have just been noticed, belong to that branch of Mechanical philosophy which is called *Optics*.

CLXIII. It has been stated by those who maintain the theory of the materiality of light, and of its independent existence, that it is capable, like other substances, of entering into combination with ponderable bodies, of forming chemical compounds, and of being again disengaged from them by the exercise of stronger affinities. Light, in fact, has been conceived to constitute a component part of all inflammable bodies, and hence the source of the luminous rays which appear during the processes of combustion. It is also presumed to be absorbed by many substances, while exposed to a source of light and particularly the solar beams, to be retained by a loose affinity, and to be again given out when removed into a dark place. Bodies, which possess the power of emitting rays of light, either spontaneously, or on exposure to a degree of heat which does not appear to influence their composition, are said to be *phosphorescent*.

CLXIV. Almost every substance in a solid state, unless it be metallic, possesses this power in a greater or less degree after exposure to the direct influence of the solar ray. The compounds in which it is exhibited to the greatest extent, are the Bolognian stone, the nitrate of lime, and the sulphuret of lime. These are called solar-phosphori. The first is formed from a variety of the mineral called sulphate of barytes or ponderous spar; indeed, all the varieties, if pure, will answer the same purpose. It is to be heated in a crucible, afterwards reduced to powder, and formed into cakes with mucilage of gum tragacanth. These cakes are dried, and then exposed to heat in a furnace filled with charcoal. When the fuel is consumed, they are collected and kept in a close vessel. When exposed to the rays of the sun and afterwards removed to a dark place, they shine with a lively phosphorescent light. Baldwin's phosphorus is merely the salt, nitrate of lime, enclosed in a phial after having been exposed to a red heat. Its illuminating power is inferior to that of the Bolognian phosphorus. Canton's phosphorus is a sulphuret of lime, which is formed by stratifying calcined oyster-shells with sulphur in a crucible, covering its mouth, and exposing it to a dull red heat for some time. This sulphuret, when preserved in a close vessel, and exposed for a minute to common day-light, sheds so much light on being removed to a dark place, as to render visible the figures upon the dial of a watch. The intensity of light emitted by the solar phosphori gradually diminishes, and at length, the luminous appearance altogether ceases. It may however be renewed by subsequent exposure to light. Cold diminishes, while heat increases their phosphorescent property. It may be remarked, and the fact is of some importance in a theoretical point of view, that to whatever kind of light these phosphori are exposed, the colour of that which they emit is uniform for each.

In other cases, the emission of light is spontaneous as in the case of dead animal and vegetable matter, and in these it is probably connected with incipient decomposition. If a few

drachms of fresh herring be put into a phial containing 2 or 3 ounces of a solution of epsom salts, and they be left at rest for 48 hours, on agitating the vessel in the dark, a mild phosphoric light will be perceptible. Decaying wood it is well known often exhibits this property in a very considerable degree. It is yet doubtful how far the power is, in this instance, dependent upon atmospheric air, for the results of experiments, which have been made to determine this point, are discordant.

There are some bodies which emit light by the action of heat alone. If the powder of fluor spar be projected upon an iron plate heated below redness, it gives out a mild and beautiful phosphorescent light. The purplish red fluor, when gently heated, produces, according to Grotthus, light of an emerald green colour, and he states that the heat of the hand alone is often sufficient for this effect. This property is likewise manifested in other bodies by friction, by percussion, and by electrical action.

CLXV. This property also characterizes some living animals. The eyes of the owl, the cat, and the wolf, shine in the dark; and many insects are enabled to emit light which is apparently dependent upon the will; such are the glow-worm of Europe, the lantern-fly of the West-Indies, and our native fire-fly. The light of the first, the *lampyrus splendidula* of Naturalists, proceeds from some of the last rings of the abdomen, and from two small sacks upon the inner side of the last ring containing a soft yellow substance. In the *candelaria* and *lanternaria*, the light is emitted from the remarkable proboscis of the fore part of the head.* The luminous substance in the fire-fly of Massachusetts is found occupying the centre of the abdomen. When taken from the animal, it preserves its power of illumination for some time. The light is emitted by the insect at intervals.

Some marine animals also appear to possess the power of emitting phosphorescent light, and the fact is familiar to those

* Nicholson's Journal, vol. xxviii. p. 41

who have crossed the ocean, that brilliant spots of light are observed in the dark, when its waters are folded into billows. This quality is often exhibited by them after death. Ferber relates, that while crossing the North Sea, the fishermen threw out their nets, which on being drawn up were found nearly filled with animals of the genera Molluscæ, and Medusæ, and that these nets which were hung up to dry were in the night highly luminous.*

In all the examples we have mentioned, the effect has been inferred to depend upon the disengagement of light which had been previously combined with the phosphorescent body, either spontaneously, by the action of caloric, by mechanical violence, by vital influence, or by a chemical change in the composition or relations of the bodies.

CLXVI. The effects which can be directly referred to the chemical agency of light are, so far as they have been investigated, both curious and interesting. To the operation of this agent it is supposed the vegetable system owes its fragrance and sapidity, its variety and beauty of colour. Plants secluded from light lose, in a greater or less degree, their colour and vigour, the proportion of solid or fibrous matter decreases, while the quantity of crude and insipid fluids increases, and they become pale and sickly. Fruits which grow in the shade, or those parts of them which rest upon the ground, are destitute of colour and nearly so of taste. In this state, they are said to be *etiolated*, or *blanched*. The same effect appears to be produced upon animals. In tropical climates, where they are exposed to the more immediate influence of light and heat, the skins of the beasts, and the plumage of the birds are more vivid and more varied than those of higher latitudes. In the winter season, the furs of animals inhabiting polar regions in many instances become white. In most quadrupeds, the under part of the body is either destitute of colour or exhibits a lighter shade than other portions of the skin, and the same remark is applicable to fishes.

* Travels in Italy.

CLXVII. In several instances, light favours chemical combination. If the two airs, chlorine and hydrogen in a dry state, be mingled, and secluded from light, no effect will follow their mixture; if they be exposed to indirect light, an union soon takes place, and when acted upon by the solar ray, this combination is produced with so much rapidity as to occasion an explosion. From this susceptibility to light, if the expression may be allowed, this mixture was employed by M. Berard as a species of thermometer to determine the relative heating powers of the different prismatic rays. A mixture of chlorine and carbonic oxide gases likewise requires the influence of light to be converted into a compound; and through the medium of the same agent phosphorus may be made to act upon gaseous ammonia.

In other cases, compounds are decomposed by light. Nitric acid, exposed to it for some time, assumes a yellowish colour; and a watery solution of chlorine becomes colourless, evolves oxygen gas, and changes to liquid muriatic acid. Light exerts a powerful influence upon the compounds of the metals with oxygen, and upon the salts formed by the union of these oxides with the acids. The lunar caustic of surgeons, the nitrate of silver of chemists, becomes black by exposure to light; hence, it is usually preserved in the shops rolled up in paper. The effect is still more positive upon the salt or compound called chloride or muriate of silver. A neutral solution of muriate of gold in water, when exposed to the direct rays of the sun, is gradually decomposed, a quantity of minute spangles of the metal appear in the liquid, and in the form of a pellicle cover its surface.* The same kind of decomposition is produced in the solutions of the salts of silver. Several of the combustible bodies, such as charcoal, and phosphorus, when aided by the influence of light, reduce the metals above mentioned to their metallic state. The colours of some of the oxides, as those of lead and of mercury, are weakened, while those of other metals are exalted by light; and by

* Scheele's Experiments on Fire and Air, p. 82.

the same agent, tartar-emetic is made to grow brown, and calomel and oxide of bismuth to acquire a tint of yellow.

CLXVIII. Light, then, or at least the radiant matter from the sun, possesses the power of decomposing bodies, and of resolving them into their elements. It has been found, however, that the effect is greater and more speedily produced in some of the prismatic rays than in others, and Mr. Scheele was the first who demonstrated this fact. He ascertained, that when a paper strewed with *luna cornea*, or muriate or chloride of silver, was exposed to the light of the coloured spectrum, the metallic compound grew black sooner in the violet ray, than in any of the other rays.* It was also proved by him that this result could not be owing to the action of the solar radiant heat; for when a phial containing the compound of silver was coated with black paint, and exposed for several days to the sun, it grew hot, but no change was perceived in the salt.† The action of the violet ray upon some of these compounds of silver is almost instantaneous; and it has been proved by Sennebier, that this has likewise the greatest effect upon the colours of vegetables. As the experiment was successively made with the different prismatic colours, it was found that in proportion to the distance from the violet ray, the effect diminished, and that it was least of all in the red ray. Whence it appears, that there is a series of chemical powers in the seven colours which commences at the red extremity of the spectrum, and increases in intensity through all the colours to the violet extremity. From the fact which had been announced relative to the maximum of the heating power being a little without the spectrum on the side of the ray, Mr. Ritter supposed that the same circumstance might happen with the chemical power on the other side of the coloured image, and on making the experiment he found this to be the case, and that the maximum power of decomposition resided without the limits of the spectrum, but near to the line of the violet ray. This result was con-

* Experiments on Fire and Air, p. 90.

† Ibid, p. 96.

firmed by Dr. Wollaston, and by the later experiments of M. Berard. When M. Berard exposed substances for a certain time to the action of each, he observed sensible effects, but the intensity decreased in proportion as they were removed from the indigo and violet rays. In order to exhibit with more effect the great disproportion which exists in this respect between the energies of the different rays, he concentrated, by means of a lens, all that part of the spectrum which extends from the green to the extreme violet; and by a second lens, all the rays which occupy the space between the green and extreme red. The last pencil formed a white point so brilliant that the eye was scarcely able to support the light; yet the muriate of silver remained exposed more than two hours to this intense light, without undergoing any sensible alteration. On the other hand, when exposed to the other pencil, which was much less hot and brilliant, it was blackened in less than six minutes. M. Berard concluded, from this experiment, that the chemical effects produced by light are not owing solely to the heat developed in the body by the combination of the light with that body; because, upon such a supposition, the faculty of producing chemical combinations and decompositions ought to be greatest in those rays which possess the faculty of heating in the greatest perfection.*

From the facts just stated it has been very generally believed that there exist in the rays of the sun, no less than three distinct species of radiant matter, viz. 1. The Colorific rays of Sir Isaac Newton. 2. The Calorific rays of Herschel and Wollaston. 3. The Chemical or de-oxidizing rays of Scheele and Ritter. But these rays all possess many properties in common, and it is an interesting subject of speculation, whether they may not be considered rather as modifications of one element, than as three specific and independent fluids.

CLXIX. In order to measure the intensity of light, instruments have been invented which are called *Photometers*; of

* Annals of Philosophy, vol. ii. p. 161

these, the most delicate is that of Mr. Leslie. Its construction and use are founded upon the principle, that light when absorbed becomes heat; or to employ the language of Mr. Leslie, that “the force of light, when not too much attenuated, may be measured by its calorific effect.”* In its form, it bears a considerable resemblance to the differential thermometer, but while one of the bulbs consists of clear, transparent glass, the other is formed of black enamel. It is graduated by an ingenious method, and protected by a glass case. When both bulbs are exposed to *heat* alone, no effect is produced upon the included air, but if *light* be admitted, the equilibrium of expansion is destroyed; for the rays freely traverse the glass bulb, while they are arrested and absorbed by the black enamel. This absorption produces an increase of heat and expansion of the air within, and the coloured liquid is pressed proportionally down the stem. This photometer is exceedingly sensible, and with all its parts constitutes one of the most delicate and beautiful of philosophical instruments. The differential thermometer may be converted into a photometer by blackening one of its bulbs.

The results of Mr. Leslie's experiments with this instrument are curious and interesting, and they may be found in his *Experimental Inquiry into the Nature and Propagation of Heat*.

* Inquiry, p. 407.



CHAPTER IV.

OF ELECTRICITY.

CLXX. When a rod of glass or a stick of sealing-wax is rubbed briskly with dry silk, it is found to have acquired the property of attracting light filamentous substances, and if the experiment be made in favourable circumstances, even flashes of light become perceptible. The power which produces this phænomenon was first observed in amber, and the name of Electricity is derived from the Greek term *Ηλεκτρον*, by which that body was designated.

If instead of glass we substitute a rod of metal or of moist wood, and subject it to friction, it will be found incapable of exhibiting any signs of electricity. This difference has been proved to obtain in a great variety of bodies, and has given rise to their classification into electrics and non-electrics.

CLXXI. If a non-electric, for example a metal, be brought into contact with an excited electric, such as glass, all electrical signs in the latter, provided the former be in connection with the ground, will disappear; but when an electric is applied, the power of attraction in the first will remain undiminished. In the former case, the electricity is said to be conducted off, and all bodies which exhibit this property are called conductors, while those in which it does not exist are considered as non-conductors of electricity. In reference, therefore, to their conducting power, bodies have been divided into two classes, and of the first, the following substances are the best in the order in which they are placed, metals, well burnt charcoal, plumbago, concentrated acids, metallic ores, animal fluids, saline solutions, smoke, steam, rarefied air. In the second class may be ranked amber, resins, sulphur, wax, jet, glass, talc, the gems, silk, wool, hair, feathers, dry paper, air and wood, porcelain. Of the conductors, the metals possess this property in so eminent a degree that all the

other bodies may be considered as imperfect conductors. Mr. Cavendish affirmed that iron-wire conducted electricity 400,000,000 times better than water, or that this power will operate as easily through 400 millions of inches of this metal, as through 1 inch of the liquid of the same diameter. Many bodies, however, owe their conducting powers to the presence of water, and it is difficult to produce signs of electricity in an atmosphere saturated with aqueous vapour.

CLXXII. When it is wished to retain the electricity which has been developed by friction or other means, the substance is placed upon a dry non-conductor, it is then said to be *insulated*, and the article commonly employed for this purpose is glass. In order to ascertain to what extent a body is electrically excited, instruments are employed, which from their office, are called *Electrometers*. They are formed of different materials, and their construction depends upon the apparent fact, that similar substances when electrified exert a mutual repulsive energy, and recede from each other, the distance to which they are repelled being proportional to the intensity of the power. The most simple of these instruments consists of two small balls made of the pith of the elder, and suspended parallel to each other by silk-threads or fine wires; sometimes only one ball is used, and in that case it is connected with a graduated arc to measure the distance to which it is repelled from the perpendicular. The electrometer which is at the same time the most convenient and delicate for common experiments, is composed of two slips of gold-leaf suspended from a brass cap attached to a cylinder of glass, the lower extremities being opposite to two laminæ of tin-foil, pasted one on each side of the glass, and connected with the metallic foot of the instrument. When these leaves are not excited, they hang parallel to, and nearly in contact with each other, but if the cap of the electrometer be touched by an excited body, they diverge, the distance to which they are separated depending upon the degree of electrical excitation.*

* Plate iv. fig. 3.

For the purpose of measuring very small degrees of electricity, the electrical balance of Coulomb should be employed. Its construction is founded upon the principles of torsion. It consists of a fine brass wire suspended from the upper surface of a glass tube, and descending below it into a cylinder of glass. The lower extremity is terminated by a small weight, and above it is fixed a small metallic bar, in a horizontal position, to one end of which is attached a gilt pith-ball, and to the other a piece of gold-leaf; the ball is placed opposite to a metallic ball connected with a bar of metal which passes out of the cylinder near its superior edge. The scale of degrees is marked upon the outside of the glass, parallel to the horizontal bar. When an excited body is brought near to, or in contact with the ball D, the metallic bar B is repelled from C, and the intensity of the electrical action is measured by the angle which is formed with its point of rest; and the sensibility of this electrometer is such, that if a stick of sealing-wax, which has been excited by friction, be brought within three feet of D, the bar or needle will be repelled more than 90°. It has been calculated that when the wire, by which it is suspended, is exceedingly fine, the force required to twist it 1° of the scale is equal only to $\frac{1}{122400}$ of a grain.*

CLXXIII. Electricity may be made manifest in bodies by changes in form and temperature, by contact and subsequent separation of dissimilar bodies, and by friction.

1. It has been found that solids, immediately after their formation, are often in an electrical state. If melted sulphur be poured into a glass, and when cool be applied to the electrometer, the gold leaves of the instrument will diverge. The same phenomenon is produced when chocolate and glacial phosphoric acid are changed from the liquid to the solid form. The production of vapour has the like effect, as may be proved by steam, for when a metallic plate sufficiently heated is placed upon the cap of the electrometer, and a few drops of water are

* Biot, *Traité de Physique Experimentale et Mathématique*, t. ii. p. 232.

Plate iv. fig. 4.

vaporised from it, the leaves repel each other and separate. The condensation of vapours likewise is accompanied with electrical phænomena.

The mineral bodies which are known by the names of *boracite* and *tourmaline*, exhibit in their ordinary state no signs of electricity, but when their temperature is augmented, this power is developed and exalted in proportion to the heat applied; and it is conjectured by Sir Humphry Davy that the luminous appearance of some diamonds when strongly heated may depend upon the same cause. The experiments of M. Dessaignes seemed to have proved that the quantity as well as the kind of electricity exhibited by bodies, is influenced by degrees of temperature.*

2. The simple contact and subsequent separation of two dissimilar bodies is often sufficient to alter their electrical states, and the phænomenon is observed after applying insulated discs of zinc and copper to each other 10 or 15 times, and bringing either into contact with the cap of the condensing electrometer.

The separation of plates even of the same nature sometimes produces electrical appearances, and it has been particularly noticed in the mineral called *mica*, which is composed of thin hexadral laminæ; for when these plates are suddenly removed from each other, they appear excited, and if the experiment be performed in the dark, bright flashes of electrical light may be occasionally observed.

3. The method, however, which is usually practised to develop and accumulate this power, is that of friction, and by a peculiar, but simple and convenient arrangement, the electricity thus produced may be employed for extensive demonstration. The electrical machine consists of a glass cylinder from 12 to 18 inches in length, and from 8 to 16 inches in diameter, and of two smooth metallic conductors of the same length, but only one third of the diameter of the cylinder; these are so placed that the cylinder shall be between them, and

* *Annales de Chimie et de Physique*, t. ii. p. 59.

they are all insulated upon glass. To one side of the cylinder is applied a cushion covered with an amalgam of tin, zinc, and mercury, and having attached to it a flap of thin oiled silk, which extends over the glass to the opposite conductor, into which is inserted a row of metallic points to receive the electricity evolved by the revolution of the cylinder. The friction between the cushion and the glass, occasioned by the motion, causes electrical excitation.

The different parts of the apparatus are thus insulated, and if in this state the cylinder be revolved, its electrical effect will be inconsiderable, and will soon reach its maximum, but if the cushion be connected with the earth by a conductor, such as a wire or a metallic chain, the electrical excitation will not only be exalted, but will continue in the same degree so long as the motion is undiminished. Now if two gilt pith-balls suspended by wires be connected with one of the conductors, they will diverge, or appear to be mutually repelled; if on the contrary there be placed one ball upon each conductor, the two will approach or be attracted toward each other, but on forming a communication between the two conductors by a wire, all motion in the balls will immediately cease, notwithstanding the continued revolution of the cylinder. In the first case then the balls, being operated upon in the same way, are said to be *similarly* electrified, and in the second to be *dissimilarly* electrified.

CLXXIV. Different bodies, when electrically excited, may by their effects upon the electrometer be made to exhibit their states of electrization, or in other words, to show whether they be similarly or dissimilarly electrified. When either glass or sealing-wax after friction is applied to the instrument, its leaves will diverge, but if the cap be touched by excited wax, after the leaves have been made to separate by the application of excited glass, they will collapse, and the converse is equally true; and if wax and glass, both electrically excited, be applied at the same time to the electrometer, no perceptible effect will take place. If gold-leaf be electrified by

contact with glass, it will recede, and will not approach while it retains its electrical state ; but in this case it will be strongly attracted by excited wax or resin, and will adhere to it with more pertinacity than to an unelectrified body. It appears, that when vitreous and resinous bodies have been exposed to friction, substances, which are attracted by the first, will be repelled by the second, and the converse, that those which are repelled by the former will be attracted by the latter, and that when the two bodies are brought into contact, a neutralization takes place, all electrical signs disappear, and the equilibrium is restored.

CLXXV. Hence it appears that the two classes of bodies, the vitreous and the resinous, are after friction dissimilarly electrified, and in reasoning from the facts then known on the subject, it was concluded by M. Du Faye that there existed in nature two distinct and subtle fluids, on which the phænomena of electricity were dependent ; he supposed that the particles of each were mutually repellent, but that the particles of both were mutually and highly attractive of each other. To the one he gave the name of vitreous and to the other that of resinous electricity. Dr. Franklin was led by his experiments and investigations to view the phænomena in a different light, and to adopt an hypothesis more simple and elegant than that of Du Faye. He inferred that the different effects produced by excited glass and resins depended, not upon the operation of two distinct fluids, but upon the different states of *one* fluid, it being redundant in the glass and deficient in the resin, that as regarded each other they were in the relation of plus and of minus, and that electrical excitation ceased when they were brought into contact, the electricity passing from one to the other and thus restoring the natural electrical equilibrium. Hence, to the vitreous, he gave the name of *Positive*, and to the resinous that of *Negative* electricity.

CLXXVI. Positive and negative then are merely relative terms intended to express a supposed fact that electricity is

accumulated in one body and proportionably withdrawn from another. The electrometer may be employed to point out the kind of electricity possessed by two dissimilar, excited bodies. If one of them be applied to the cap of the instrument, the leaves will diverge; bring the other into contact with it, and if the leaves diverge still further, the bodies are similarly electrified; if they collapse they are in opposite electrical states, or one is positive, the other negative. Resins cause the leaves to collapse which had been previously separated by excited glass; the latter is positive, the former negative. When light accompanies electrical action, the cause of the spark has been supposed to point out the different electrical states. If the hand be held opposite to the prime conductor of an electrical machine in motion, a spark will pass between them from the conductor to the hand. Hence, the former is considered as positive, the latter as negative. It has been supposed also that the kind of electricity may be ascertained by the appearances of the body presented to an electrified surface. If a pointed wire be opposed to a body negatively excited, a diverging pencil of rays will seem to pass from the former to the latter; on the contrary, if the body be positively electrified, the point of the wire will be illuminated by a well defined star or sphere of light.

CLXXVII. According to the hypothesis of Franklin, electrical phenomena may be produced either by varying the quantity contained in a body, or by causing an unequal distribution of its natural electricity in different parts.

When two bodies which are non-conductors are rubbed together and then separated, they are found to be electrically excited, and while one is positive, the other is proportionally negative; a portion, therefore, of the electricity of the latter, has passed into the former, and the natural quantity of each is altered.

The phenomena exhibited by the Leyden jar is supposed to illustrate the second of these modes. It consists of a

cylindrical glass jar, coated both internally and externally with tin-foil to within 2 or 3 inches of the upper edge ; a rod of brass, having a knob or ball on the upper end is introduced through the covering of the jar, so that it shall be in contact with the internal coat ; and to the external and lower part is fitted a ring to connect it with the ground or with one of the conductors of the machine.* Now if the jar be insulated and the knob be placed in communication with the positive conductor of a machine in motion, while the external coating is connected with the cushion, the inner surface will become positively electrified ; in proportion as this takes place, the external surface exhibits negative electricity, and if the jar be removed from the machine and a communication by a conductor be established between the two surfaces, a vivid spark will be perceived, and all electrical signs will disappear. It is supposed then that the electricity, in this experiment, is drawn from the outer surface, which becomes negative, and accumulated on the inner surface which is rendered proportionably positive, and that when a communication is established between them, the fluid passes from the latter to the former, and the electrical equilibrium is restored. The jar is here charged without communication with the ground.

CLXXVIII. The second mode also obtains when an insulated conductor is brought *near* to an electrified body ; the electricity in the former is said to be “disturbed,” and rendered irregular, the conductor being oppositely electrified at the surface nearest to the body, similarly electrified at the remote surface, and neutral at the middle point. These phenomena may be observed when a number of insulated cylinders of the same size, and placed in a line, are brought near to an highly electrified conductor, the last cylinder being in connexion with the ground. The ends of the cylinders opposed to the conductor will all be found in one state of electricity, while the ends directed from the conductor will exhibit the other state, and if a spark be seen between the conductor

* Plate iv. fig. 6.

and the first cylinder, it will be equally visible between all the other cylinders.*

The electrical *Condenser* has been supposed to exhibit its effects in consequence of its electrical arrangement being disturbed by the proximity of the electrified body to an insulated conductor. It consists of two plates of polished brass, one of them being insulated upon a stand of glass, while the other is connected with the foot of the instrument by a brass rod which is jointed, to allow of its separation from the insulated disc. The plates are placed parallel, nearly in contact and in connection with the electrometer. The insulated plate is touched by an excited body, and on withdrawing the plates from each other, electrical signs are made manifest in the leaves of the electrometer. These plates are more conveniently employed when they are immediately in contact with the electrometer, one of them being connected with the cap, the other with the foot of the instrument. It then constitutes the *Condensing Electrometer*.† On this principle of electrical influence, as it has been termed, depends the explanation of electrical discharges, of the spark, and of lightning.

It is predicated on the hypothesis of the existence of a single fluid, the particles or atoms of which are highly repellent, while they are equally attractive of those of ponderable matter. It infers, that when an excited body is brought near to a conductor, the electric fluid in the latter is set in motion; it is repelled from the part nearest to the body, and accumulated proportionably at the most remote surface; hence supposing the electrified body to be in the positive state, the nearest point of the conductor will be negative, the opposite extremity will be positive, and the middle part must be neutral.

CLXXIX. It appears, however, by more accurate and extensive researches into electrical phenomena, that the effects may be as well, if not better explained on the assumption of the existence of two fluids as of one fluid, and as both of these

* Plate v. fig. 1.

† Plate iv. fig. 5.

hypotheses present difficulties, which in the present state of the science, cannot be surmounted, it is perhaps more philosophical to confine ourselves to a simple enunciation of facts, and to consider electricity as a property of matter which requires certain conditions of bodies to be developed.

CLXXX. The two electrical states, viz. the positive and negative are always produced where there are signs of electrical excitement ; they are coincident, and appear to be equal, or just sufficient when a communication is made between them to re-establish the electrical equilibrium. One state, therefore, induces the other ; if the cylinder of a machine be revolved, one conductor will be positive, the other negative, but both states will be removed, provided a communication by a wire be made between them ; if a conductor be opposed to an excited body, a stratum of air, which is an imperfect conductor being interposed, the phænomena already mentioned will take place by induction ; if the human body be the conductor, a state opposite to that of the electrified surface will be induced, and the two states will continue to be exalted, until the polarities, as they have been termed, are annihilated through the air, producing a spark, a snap, and a distinct sensation. The phænomena displayed by the line of cylinders, the Leyden jar, by thunder-storms, water-spouts, and the Aurora Borealis, and Aurora Australis, have all been explained upon *induced* electricity.* This term is intended merely to express a fact that when a conductor is brought into the neighbourhood of an excited body, electrical excitement is evinced in the conductor itself. How these phænomena are produced cannot be explained, but they may be considered as dependent upon the electrically attractive and repellent powers inherent in matter.

“ In electrical action, the power appears to be confined to the surfaces of bodies, and it is not connected with the quantity of matter they contain. Large surfaces are electrified by induction much more slowly than small ones, and are capable

* Davy's Elements, p. 130, et seq.

of accumulating much more electricity, which renders the discharge from them much more violent."

CLXXXI. As the terms poles and polarity will be frequently employed in the following pages, it is necessary to have a clear idea of their signification. They are derived from the science of magnetism, and may be illustrated by some of its phenomena. When a magnetized needle is freely suspended, it moves upon its pivot until it is parallel with the transverse diameter of the earth, one end pointing north and the other south; to the former is given the name of north pole, and to the latter that of south pole. If a few small and flattened pieces of iron be placed upon the surface of water or of mercury, they will float upon it indifferently, in any position, but when two powerful magnets are brought near them, so that they may be acted upon by their opposite poles, they will arrange themselves in a line in regular order; each wire will have a north and a south pole, and the south pole of one will be opposed to the north pole of the other, and they will be mutually attractive. If either the north or south pole of the magnet be presented to the same pole of a filament, repulsion will take place. If an insulated conductor be opposed to an electrified body, it will be excited, the point nearest the body will be dissimilarly electrified, the other extremity will be similarly electrified, and the middle neutral. The conductor may in that state be said to have received polarity; one end is called the positive, and the other the negative pole. This polar arrangement may extend to the particles of matter in cases in which they are said to be electrified, and there must be of course an indefinite alternation of poles.

CLXXXII. The difference, says Sir H. Davy, in what are called the Conducting powers of bodies, seems to depend entirely upon the different manner with which they receive the electrical polarities, or by which their parts become capable of communicating attractive or repellent powers to other matter. Non-conductors appear to receive polarities only with great difficulty, and retain them for a long while, and present

probably a number of different alternations of poles within a short space, and cannot be affected to any great distance. Imperfect conductors receive polarity with more facility, but present fewer alternations, and preserve their electricities for a shorter time. Perfect conductors are easily affected throughout, but preserve at most only two poles, and the powers rapidly destroy each other. Rarefied air, or gaseous matter is much more susceptible of receiving polarities than dense air, or gaseous matter, and hence the electrical spark will pass much further through rarefied air or light gases, than through dense air or heavy gases; it passes much further likewise in gases, than in non-conducting (*imperfectly conducting*) fluids.*

CLXXXIII. If a Leyden jar charged to such a degree as to give a spark 1 inch in length, be connected by both of its conducting surfaces with an uncharged jar of the same capacity, it will be found that both may be discharged together, but that in this case the spark will be only one half as long as when the electricity is drawn from one of them. Now it is obvious that the *quantity* of electricity in both instances is the same, but that in the latter case, the power of this principle to overcome the resistance of an imperfectly conducting medium, such as air, is reduced one half. To this power has been applied the name of *intensity*. The difference between quantity and intensity appears to be this, that the former is meant to designate the whole amount of electricity accumulated in any body or system of bodies, while the latter is appropriated to the property of being transmitted through a greater or smaller space in media, the conducting powers of which are comparatively feeble. This difference will be again adverted to when we come to the subject of galvanic arrangements, but it may be remarked that in the Voltaic apparatus a few large plates exhibit little intensity of action, but if they be cut down into smaller ones, the intensity is highly augmented; now in both cases the surface being the same, the quantity of electricity evolved must be similar, but in conse-

* Elements, p. 136.

quence of the increase of imperfectly conducting matter, the intensity in the arrangement with the small plates, will be proportionably exalted. Upon what property of electricity this difference between quantity and intensity depends, it is at present difficult if not impossible to determine ; but it is not the less necessary to keep in mind the distinction because, without involving any hypothesis, they may be considered as expressions for general facts, and these facts must be employed in the explanation of many of the phænomena of Electricity.

CLXXXIV. We shall now pass to some of the effects of electricity. The mechanical action of this power, when in a state of high intensity, is very remarkable. It will perforate solid bodies of considerable thickness without communicating to them any sensible motion. It may be so managed as to fracture the hardest substances, and, by the expansion which it occasions in liquids, to rend asunder the strongest tubes of glass and even of metal, dispersing their contents and twisting and contorting the metals in the most curious and unaccountable manner.

CLXXXV. The chemical effects are equally surprising and in many instances appear to be owing to the high temperature produced in the electrical circuit. It will inflame gun-powder and some of the volatile liquids, such as ether and alcohol. When it operates in a state of high intensity upon small wires, it renders them red hot or even melts, and dissipates them in minute globules, the effect increasing in the ratio of the square of the increased power.* The metals thus melted frequently take fire, and at the conclusion of the experiment are found in the state of oxide. When thus produced they have sometimes been called Electroxides. They are, if we may judge from their colours, mixtures of oxides and the metals in a state of extreme division. The colours are the following ; of gold, purple and brown ; of silver, grey, brown and green ; of copper, green, yellow and

* Singer's Elements of Electricity, p. 177.

brown ; of iron, light brown ; of tin, yellow and brown ; of brass, purple and brown.

Electricity has also been made the instrument of decomposition, operating upon compound matter and resolving it into its elements. Water, inflammable liquids and metallic saline solutions may be thus decomposed ; and the same effect is produced upon compound gaseous matter. Ammonia may be resolved into hydrogen and nitrogen ; sulphuretted, phosphuretted, and carburetted hydrogen respectively into sulphur, phosphorus, carbon, and hydrogen ; and carbonic acid into oxygen and carbonic oxide.

On the other hand, when gaseous matters, which have an attraction for each other are mingled and subjected to electrical action, combination will take place and a compound be formed. Thus oxygen and hydrogen gases are condensed into water, oxygen and nitrogen into nitric acid, oxygen and sulphurous acid into sulphuric acid, atmospheric air and hydrogen into water and nitrogen, and oxygen and carbonic oxide into carbonic acid.

These results are obtained by the use of the Eudiometric tube, which consists of a strong glass vessel 10 or 12 inches in length and about three quarters of an inch in diameter. It is hermetically sealed at one extremity, but open at the other, and somewhat expanded for the purpose of support. About half an inch from the upper end it is perforated on opposite sides to allow of the introduction of two wires, the ends of which on the inside are brought within $\frac{1}{4}$ of an inch of each other. Cement is applied to render the perforations airtight. The tube is graduated into cubic inches and tenths.* When it is to be employed, it is filled with water or mercury, according to the nature of the gases to be submitted to experiment, and placed on the shelf of the hydro-pneumatic, or the mercurial apparatus, the gas or gases are introduced, and the wires being then respectively connected with the surfaces of a charged jar, the spark is taken through the airs. In

* Plate v. fig. 2.

some cases the combination is so rapid as to produce explosion, as in the case of oxygen and hydrogen ; in others it requires repeated applications of electricity, as in the production of nitric acid from a mixture of oxygen and nitrogen gases.

CLXXXVI. As the effect of electricity on bodies is often exhibited in a sudden and great expansion, the old opinion of *Cold Fusion* has been revived by M. Berthollet, who supposes that it does not act by increasing the temperature, but “by a dilatation which separates the *moleculæ* of bodies.”* The phænomena presented by wires in this experiment, however, are adverse to this hypothesis, and it seems to be invalidated by the fact, that water, surrounding a perfect conductor strongly electrified, may be made to boil.

CLXXXVII. Electrical discharges, when the power exists in any intensity, are always associated with light. The electric spark is well known ; it is white with a tinge of violet. The distance to which it will pass depends upon the intensity and the medium. It traverses rarefied media with less difficulty than those which are denser, and hence it may be transmitted through hydrogen gas several feet. Light is visible even in a torricellian vacuum when it constitutes a part of the electrical circuit. Electrical light has all the properties of light derived from other sources. It operates in the same way upon the organ of vision, it is susceptible of reflection and refraction, and it may be resolved by the powers of the prism, into the seven primary rays.

Electricity will even render bodies phosphorescent. A strong charge transmitted over the following bodies caused them to shine for some time afterward, the colour of the light depending upon the nature of the substance. Thus ponderous spar exhibited a bright green light, sulphuret of lime white light, rock-crystal, red, then white, borax, faint green, boracic acid, bright green, quartz, dull white, and calcined oyster-shells, the colours of the rainbow.†

* Chemical Statics, vol. i. note xi.

† Singer's Elements of Electricity, p. 201.

But the common electrical machine is not the best arrangement which can be employed to exhibit the agencies of electricity in producing chemical phenomena, and in arriving at the elements of bodies. It is inconvenient, difficult to manage, and the power is not so completely under the controul of the operator, as to enable him to proceed with facility in a series of uniform and uninterrupted applications. Hence it has been laid aside since the chemist has obtained possession of an instrument, by which all the chemical changes, connected with electricity, may be more easily demonstrated. This instrument is the *Voltaic apparatus* or *battery*.

CLXXXVIII. In the year 1791, Sig. Galvani, professor of Anatomy at Bologna, accidentally discovered, that a slight charge of electricity sent through the limbs of a frog recently killed, produced strong muscular contractions. He proved that these contractions might be excited independently of the machine, by coating a nerve with tin-foil and forming a communication, by means of a conductor, between the metal and the muscles attached to the limb. From these and other experiments he concluded that electricity is secreted by the brain and distributed over the system, that the different parts of muscles are in different states, that electricity is accumulated in one part and withdrawn from the other, and that by forming an electrical communication between them, the equilibrium is restored, the electricity in its passage acting as a stimulant upon the irritable fibre and producing contraction. The hypothesis of animal electricity was thus brought into vogue, and the power which occasioned these contractions was called, in honour of the discoverer, Galvanism.

CLXXXIX. This hypothesis was adopted and amplified by some of the Italian philosophers, but in 1793 it was shown by Volta, that Galvani reasoned erroneously from his experiments, and that the muscular contractions were owing, not to any power inherent in the animal fibre and equalized by a conductor of electricity, but simply to the contact of two dissimilar metallic bodies, the animal substance introduced into

the arrangement merely operating by its irritability to render evident the small quantities of electricity evolved in these combinations. That electrical signs may be produced by the simple contact of two metals had been shown by Sultzer and by Bennet. If a plate of silver be placed under, and a plate of zinc over the tongue and they be brought into contact at the extremity of that organ, at the moment of contact a slight shock and a peculiar taste will be perceived, and if the surfaces be extensive, even a flash of light will be observed. If a plate of zinc and a plate of copper, both insulated on glass, be alternately applied to and removed from each other, it will be found that after 15 or 20 contacts, on touching the cap of the condensing electrometer with either and separating the plates, the gold leaves will diverge. Hence, if after these contacts of the zinc and copper plates, the limb of a frog, recently killed, be employed as the medium of connexion, the electricity in acquiring its equilibrium will act upon the irritable fibres, and produce muscular contractions. These contractions then are owing merely to the electrical action which takes place in consequence of the different states of electricity acquired by contact, and the equilibrium of which is restored by the conducting power of the animal substance.

CXC. Much discussion took place, and many experiments were instituted between the years 1793 and 1800. in support of the hypotheses of Galvani, of Volta, and of Fabroni, who referred all the effects to chemical action; but at length the opinions of the Bolognian philosopher were put to rest by the great discovery of Volta, of a mode of arranging dissimilar metals so as to exalt the two electrical states to almost any degree of intensity. He has thus given to philosophy a new power; he has opened to the chemist a novel and brilliant path, and in return, the chemist and the philosopher have gratefully bestowed upon this principle the name of Voltaic electricity.

The instrument which was formed by Volta to accumulate the electricity produced by the contact of dissimilar metals is

called the *pile*. It is constructed in the following way. On a stand is placed a plate of silver, and upon this a plate of zinc of the same size ; to the zinc is applied a disc of cloth, or of pasteboard of the same diameter, moistened with a solution of common salt, or sal ammoniac, or with a diluted acid. Upon the cloth rests a second piece of silver, which supports a piece of zinc which, in its turn, is covered with moistened cloth or pasteboard ; so that the series consists of silver, zinc, moistened pasteboard, silver, zinc, pasteboard, and in this mode of arrangement the pile may be reared to any convenient height. It is essential that the order adopted in the first series should be preserved throughout the column, for if it be inverted in any part, i. e. the silver on the zinc, each part will be found to constitute an independent arrangement.*

Zinc and silver were first employed, and they form the most powerful pile, but copper is now universally substituted for the last metal, and the small difference in power is more than counterbalanced by the difference in expense.

Volta also invented another simple apparatus for showing the effects of Voltaic electricity. It is called the *Couronne de Tasses*, or Circle of wine-glasses or cups. It consists of a row of cups or wine-glasses containing some saline solution ; on one side of the glass is a zinc plate, having attached to it a wire which passes into a second glass and terminates in contact with a plate of copper ; on the opposite side of the last glass is a plate of zinc, which is connected with a plate of copper in a third glass by a wire, and thus each glass contains two plates, one of zinc, the other of copper. In this way a Voltaic series, possessing weak electrical powers may be formed.

CXCI. The pile has in a great measure been superseded by the *Trough* or battery of Mr. Cruickshank of Woolwich. In constructing this apparatus the zinc and copper plates are previously soldered together, one of each, so as to form a double plate ; these are fixed by a cement of wax and resin in-

* Plate v. fig. 1.

to grooves cut in a trough of well seasoned mahogany, the spaces between them, or the cells, as they are called, being from one half of an inch to an inch in width. The liquid with which these cells are filled bears the same relation to the compound plates, as the moistened discs of pasteboard to the metals in the pile of Volta. The same care is here also requisite in the arrangement of the plates, the zinc being always directed toward one end, and the copper toward the other end of the trough. The common troughs contain about 50 double plates from $2\frac{1}{2}$ to 4 inches in diameter.*

CXCII. In consequence of hypothetical views respecting the mode in which electrical excitation takes place in the voltaic apparatus it has been supposed, that the power would be considerably increased if not doubled, by separating the plates so as to expose both surfaces of each to the action of the interposed liquid. Accordingly partitions of glass have been employed, the plate of zinc being on one side, and the plate of copper on the other, a communication being made between them by a metallic clasp. But as the partitions are very liable to injury, an improvement has been made in substituting for the mahogany battery troughs of Wedgewood's ware, which has the great advantage of insulating the Voltaic series. Each trough is divided into ten cells by partitions of ware; the zinc and copper plates are soldered together only at one point, and by means of screws are fixed in a rod of mahogany which lies longitudinally over the trough. The whole is protected by a wooden case which has attached to it stands of iron or of wood, on which the frame supporting the plates may be hung, when the action of the battery is not required.† The magnificent apparatus, belonging to the Royal Institution of London, is constructed upon this plan. It consists of 200 instruments, connected together in regular order, each composed of ten double plates arranged in cells of porcelain, and each plate exposing a surface equal to 32 square inches;

* Plate v. fig. 2. † Ibid, fig. 3.

so that the whole number of double plates is 2000, and the whole surface 128,000 square inches.*

A very powerful battery was constructed by order of the French Government consisting of 600 pairs of plates, each nearly eleven inches in diameter, and exposing altogether nearly 500 feet of surface; and when required, this battery might be connected with a smaller one composed of 1500 pairs of plates.

The most gigantic battery ever constructed to exhibit only a part of the operation of Voltaic electricity, is that of Mr. Children of Great Britain. It has only 20 pairs, or rather triads, but each plate is six feet long, and two feet eight inches wide, and each pair exposes a surface equal to 32 square feet. They are arranged in wooden troughs connected by leaden clasps, and so placed that one zinc plate is between two copper plates in the same cell. The plates are poised by weights so that they may be elevated or depressed at pleasure.

In opposition to this we may place the Elementary Galvanic battery of Dr. Wollaston. It is formed of a silver thimble, without the top; its sides are brought within $\frac{2}{10}$ of an inch of each other, its length is $\frac{9}{10}$ of an inch; the zinc plate, to which is soldered a little apparatus of wires for forming the communication, is less than $\frac{3}{4}$ of a square inch in dimensions. This apparatus is supplied with two conducting wires $\frac{1}{40}$ of an inch in diameter; when this battery is insulated, and moistened with diluted sulphuric acid, the electrical excitation is sufficiently intense to melt platina wire $\frac{1}{3000}$ of an inch in diameter.

CXCIII. The Electric Columns of De Luc and of Zamboni are weak Voltaic combinations, which probably owe their powers to the presence of a small quantity of water, to the circulation of atmospheric air, or to the chemical action of the materials of which they are composed. Mr. De Luc formed what he called a dry pile, by mounting in a column discs of tinned iron with the same number of discs of Dutch

* Davy's Elements, Part i. p. 152. Eng. ed.

gilt-paper between them, the gilt sides being disposed in one direction throughout the series, so that it was composed of the series tinned iron, copper, paper, and in a pile consisting of 800 of each, the electrical excitation was found to be more powerful than existed in any Voltaic battery which he had tried. Mr. Singer recommends, as the best materials for these columns, thin plates of flattened zinc alternated with writing or smooth cartridge paper and silver-leaf. The leaf is first laid on the paper, discs are then cut from the zinc and silvered paper about $\frac{5}{8}$ of an inch in diameter, and they are arranged in the order of zinc, paper, silvered paper, with the silvered side upward; zinc, upon this, silver, then paper, and again silvered paper with the silvered side upward, and so on, the silver being in contact with the zinc throughout, and each pair of zinc and silver plates separated by *two* discs of paper from the next pair. A column of 1000 or 1600 of these may be secured by three thin glass rods, afterwards introduced into a dry glass tube surmounted with caps of brass, and having screws attached to them to keep the plates in contact. The column may be insulated on glass.* If such a column be made to rest at each extremity upon an electrometer, the gold leaves of both will diverge, one with positive, the other with negative electricity; the former being touched by the zinc end, and the latter by the silvered end of the column. Two such columns may be placed perpendicularly within 2 or 3 inches of each other, the zinc end of one, and the silvered end of the other being connected by a conductor of electricity at the top, and if a delicate metallic clapper be suspended between them, a small bell being attached to the foot of each column, the clapper will be alternately attracted from one to the other, producing a perpetual but irregular chime. No limits have yet been discovered to this motion. A combination of this kind containing 20,000 pairs, erected by Mr. Singer, affected pith-balls, produced a spark, charged a jar which gave a considerable shock.

* Singer's Electricity, p. 452.

and melted one inch of very fine platina wire. But it produced no sensible chemical effect.*

Zamboni's column, an account of which was published two years after De Luc's memoir, is formed of discs of silvered paper, and of oxide of manganese rubbed with honey and applied to the paper side, so that the series consists of silver, paper, oxide of manganese. About 2000 of these are mounted, they are then covered with a varnish of shell-lac and inclosed in a glass tube. These may be combined with each other and with a bell-ringing apparatus similar to that above mentioned. It has been proposed to constitute the electricity of these columns, a moving power for clocks, but the motions are so irregular that no dependance could be placed upon their results. They are not affected by the electrical state of the atmosphere.

CXCIV. It was ascertained by Volta, that electrical excitation might be produced in any circle composed of three bodies of different conducting powers ; hence it may be made to appear when only one metal is employed with two dissimilar fluids, or one metal, one liquid, and one solid not metallic. In generalizing these combinations, it appears that they may be formed into two classes ; the first comprising dry and perfect conductors ; the second, imperfect conductors, as liquids and fibrous solids, which owe their conducting powers to the liquids they contain. A proper Voltaic combination consists of three bodies taken from these two classes. When two perfect conductors are combined with one imperfect conductor, the combination is said to be of the First order ; combinations of the Second order are formed of two imperfect conductors and one perfect conductor. These different arrangements are illustrated in the following tables from the work of Sir H. Davy.

* Nicholson's Journal, vol. xxxv. p. 85.

Plate v. fig. 4.

Combinations of the First order.

Zinc	Each of these is positive to all the metals below it, and negative with respect to the metals above it, in the column.	Sol. of Nitric acid
Iron		Muriatic acid
Tin		Sulphuric acid
Lead		Sal ammoniac
Copper		Nitre
Silver		Other neutral salts.
Gold		
Platina		
Charcoal		

Combinations of the Second order.

Sol. Sulph. & Potash Potash Soda	Copper	Nitric acid
	Silver	Sulphuric acid
	Lead	Muriatic acid
	Tin	Any solutions containing acids.
	Zinc	
	Other metals	
	Charcoal	

CXCV. It will be seen then that all the combinations which have been described, belong to the First order, in which two perfect conductors, such as zinc and copper, are combined with one imperfect conductor, as a liquid. But the organs of some animals, which are known to give an electrical shock, come under the Second class. Such is the apparatus of the Torpedo, the Silurus and the Gymnotus Electricus. The Torpedo is of the Order of Rays, and is found in the waters of the Mediterranean, and of the North of Europe. Its weight is from 18 to 20 pounds. The organ in which the electrical power resides is composed of a great number of columns, divided horizontally by partitions, and exposing a great extent of surface. In the full grown animal, the number of columns has been found to amount to between 1400 and 1500. The spaces between them appear to contain a fluid, and it is sup-

posed that the occasional propulsion of this liquid into the interstices, by which an extensive contact between two dissimilar bodies is suddenly effected, may give rise to electrical phenomena.

The *Gymnotus Electricus*, or Surinam Eel, is usually about 3 feet in length, but is sometimes seen much larger, and the shock given by it is then said to be sufficiently powerful to kill a man. Mr. Hunter found its electrical organ to be more simple in construction, than that of the Torpedo. In both of these animals, the nerves leading to these organs are much larger than those appropriated to any other part of the body. The evolution of electricity is entirely under the controul of these animals, and its communication is always accompanied with a depression of the eyes. The shocks succeed each other with considerable rapidity, fifty of them having been counted in a minute and a half.

CXCVI. In preparing the Voltaic battery for experiment, the cells are filled with a liquid which is known to act chemically upon the plates. It may consist, therefore, of a saline solution, or of a diluted acid. The action of a solution of common salt or sal ammoniac is not so powerful as that of a diluted acid, but it continues longer, and a cheap and effectual liquid may be obtained by adding to the first of these solutions a small proportion of muriatic acid. Sulphuric acid, diluted with 50 or 60 parts of water, has a powerful effect, but its action is sooner weakened than that of water containing $\frac{1}{40}$ of nitric acid. Upon the whole, however, muriatic acid diluted with 30 parts of water has been found the most useful Voltaic liquid.

The singular and curious fact has been discovered by Mr. Porrett, that after the action of the liquid and the plates in the trough has ceased, the apparatus may be again rendered active by drawing off nearly the whole of the fluid contained in the cells.

CXCVII. When the apparatus is thus arranged, it will be found that the two extremities or poles are in opposite elec-

trical states, the zinc always being positive, and the copper always negative. By the condenser, these facts may be demonstrated by a few plates, but with a series of fifty pairs, the gold-leaves of the electrometer will diverge when connected with them, even independently of the condenser. If the number of plates amounts to 800, even pith-balls will diverge. On bringing the ends of two wires connected with the two poles of such a battery nearly into contact, a bright spark will be perceived, and on forming a communication with a Leyden jar, by connecting the wires respectively with its two coatings, it will be charged by a single momentary contact to the same intensity as the battery itself. When the hands are well moistened, and are brought into contact, the one with the positive, the other with the negative pole, a shock will be experienced, proportional to the number of plates; the shock from a battery of 400 plates is exceedingly violent. If the wires be terminated by cones of dry charcoal, made from box-wood, on forming the communication, sparks will be produced, and part of the charcoal will become red hot. When pieces of this substance, about an inch in length, and $\frac{1}{8}$ of an inch in diameter, were connected respectively with the positive and negative poles of the great battery of the Royal Institution, and brought very near each other, a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness, and, by withdrawing the points from each other, a constant discharge took place through the heated air, in a space equal at least to four inches, producing a most brilliant ascending arch of light, broad and conical in the middle.*

CXCVIII. The temperature excited in the circuit of batteries which are composed of a very large number of small plates, or of a small number of large plates, is intensely high. The power to ignite bodies was almost equally apparent in a battery consisting of 2000 double plates, each exposing a surface of 32 square inches, and in Mr. Children's arrangement

* Davy's Elements, p. 153.

each triad exhibiting a surface of 32 square feet. By the former, platina, one of the most infusible of bodies, was melted in the arch of flame as readily as wax in the flame of a common candle ; quartz, the sapphire, magnesia, and lime, all entered into fusion ; fragments of diamond, and points of plumbago and charcoal rapidly disappeared, and seemed to evaporate. By the latter, $8\frac{1}{2}$ feet of platina wire 0.44 of an inch thick were heated red hot ; in small quantities it became bright red and melted at the ends ; some of the most refractory oxides were reduced, and the most difficultly fusible metals melted into globules.

The metals when reduced to very thin leaves do not require for their ignition or combustion, that the power should be very high. Gold and silver-leaf may be consumed, the one giving forth a brilliant yellow, the other a beautiful greenish white light, by connecting them with the poles of a battery composed of 100 double plates of 3 or 4 inches.

CXCIX. The chemical effects of the Voltaic apparatus are wonderful. Its operation is gradual but continued, and no form of matter, if compounded, is able to resist its action. Compounds in the liquid state are decomposed with facility ; but even insoluble compounds and the hardest and most solid aggregates are finally resolved into their elements by the decomposing power of Voltaic electricity.

CC. If two wires of gold or platina be connected with the respective poles of a battery, and their points be immersed in a vessel of water, but not so as to touch each other, a stream of minute bubbles will be seen to rise from each, but in largest quantity from the one which is in communication with the negative pole. By conducting this experiment in a tube, the airs may be obtained in a state of mixture, and on applying a flame, the gases will explode, and be condensed into water. This important experiment was first performed by Mess. Nicholson and Carlisle. If the battery be extensive, the mixed gases may be fired by inclining the tube, and bringing the ends of the wires sufficiently near each other to allow of

the passage of a spark. The airs evolved are in the proportion necessary to form water, viz. one volume of oxygen, and two volumes of hydrogen. These gases then result from the decomposition of the water by the action of Voltaic electricity. They may be obtained in separate receivers by using a simple apparatus contrived by Dr. Wollaston.*

This decomposition may be made to proceed in two different vessels, the oxygen being evolved in one, and the hydrogen gas in the other, by connecting the two by means of moistened cotton, or asbestos.

Such is the power of electricity in this respect, that when the two wires are in the same tube, the decomposition will take place even when the space between them amounts to 3 feet.

CCI. If, instead of gold and platina, wires be employed of metals which have strong affinities for oxygen, such for example as iron, hydrogen will as usual be observed to rise from the negative pole, but no gas will be seen from the positive pole; on the contrary, the metal will appear corroded, and a substance will form on its surface having the characters of an oxide of iron. If silver wires and well-water be employed, a turbidness will soon take place in consequence of the decomposition of the muriatic salts held in solution, and the formation of an insoluble *Chloride of silver*.

With wires of some other metals, no hydrogen is apparently produced at the negative wire, but the metal becomes changed in its appearance, and there are strong grounds for believing that a solid compound is formed during the experiment of hydrogen and the metal. Such is the case with tellurium, and the compound is called an *Hydruret*.

By arrangements similar to the above, many other liquids may be decomposed, and their elements collected. Thus liquid ammonia furnishes oxygen, nitrogen, and hydrogen gases; muriatic acid, chlorine and hydrogen; nitric acid, oxygen and nitrogen; sulphuric acid, oxygen and sulphur.

* Plate v. fig. 5.

CCII. It was ascertained by Mr. Cruickshank, that metallic solutions might be decomposed by the agency of Voltaic electricity. These decompositions may be exhibited in glass tubes alone, or in tubes connected with a simple apparatus consisting of a flat-bottomed brass cup having a thick wire screwed into it one or two inches in length; the upper part of the wire is divided to allow of the insertion of a smaller wire of gold or platina; a tube of glass closed at one end and having a wire passing through the cork, is filled with the metallic solution, and inverted over the wire in the cup, the ends of the wires being separated from each other, to the distance of about an inch. The wires are then connected with the battery; and in none of these experiments is gas seen to rise from the negative pole, but it soon exhibits the reduced metal. When solution of blue vitriol is employed, the wire becomes coated with a film of metallic copper; solution of nitrate of silver produces a fleecy deposit of silver; the effect, when muriate of tin is used, is beautiful, and solution of sugar of lead affords the same appearances, fine and delicate crystals of metallic lead shooting out from the point of the wire in the form of a star or coronet.

It has long been known that the metals are capable of precipitating each other from their acid solutions, and that in such cases, the oxygen and the acid of one are transferred to the other. If a plate of copper be immersed in a solution of nitrate of silver, its surface will soon become covered with a precipitate of reduced silver, and by a peculiar arrangement, this deposition may be made to take place at a considerable distance from the precipitating metal. When a piece of copper coin is immersed in the solution of nitrate of silver which rests upon a plane surface of glass, its edges will be surrounded with a circle of metallic silver, which continually enlarging, finally branches out in the form of beautiful arborizations to the distance of two or three inches from the surface of the copper. The same general effect is observed when a mass of zinc is suspended in a solution of sugar or

acetate of lead ; for fine and delicate plates or laminæ of reduced lead will be seen to form from the lower surface of the zinc, the distance continually increasing until the solution of the salt of lead is entirely decomposed, and changed into a solution of acetate of zinc.

These changes may also be produced in a very pleasing and striking manner in the experiments of Mr. Sylvester and of M. De Grotthus. The former covered one half of a pane of glass with solution of nitrate of silver, and the other half with diluted muriatic acid ; one end of a platina wire was immersed in the solution while the other rested upon the table, and a zinc wire was similarly placed with one extremity in the acid. On making a communication by a conductor of electricity between the two wires, a beautiful arborescent deposit of silver was occasioned around the wire of platina.*

In all these cases the particles of the metal which is separated are at first in contact with those which produce the decomposition, but as the action proceeds, the laminæ or filaments of the former increase in length, and, as is shown in the *lead-tree*, they finally extend several inches from the precipitating surface.

In examining these phænomena, the opinion of Grotthus will probably be considered as correct, that the elongation is in such cases the consequence of the super-position of the particles of the reduced metal upon each other. He instituted many experiments to prove the correctness of this conclusion, and among them the following appears to have been the most decisive and the most beautiful. Into a tube about 6 inches high, and $\frac{1}{4}$ of an inch in diameter, was poured a concentrated solution of nitrate of copper until it filled one half, the remaining half was cautiously filled with a neutral but not dense solution of nitrate of silver, which had been previously mixed with a little alcohol, to diminish its specific gravity. The two liquids were therefore in the same tube, but perfectly distinct from each other, the lowest being of a fine blue

* Nicholson's Journal, vol. xiv. p. 94.

colour, and the highest, colourless and transparent. A cylinder of copper was then let down into the tube, and allowed to remain in the middle of the nitric solution of silver; in a short time the silver began to precipitate in its metallic state, the chains of silver flowers gradually approached the blue solution of copper, and in twenty-four hours, their extremities were distinctly covered with particles of metallic copper. The tree of Diana, which in this experiment, as he poetically expresses himself, appeared to be transplanted into the garden of the Hesperides, acquired in four days an increase of a quarter of an inch in length, the colour and ramification of which were unquestionably those of copper. When a cylinder of zinc was substituted for the copper, the effect was much more speedy.* The experiments of Mr. Sylvester, and of De Grotthus, upon this subject, led them to conclude, that the precipitations were occasioned by a Galvanic action, and this opinion has been universally admitted as correct.

Some very curious facts respecting the mutual operation of metals immersed in acid media have been brought forward by Mr. Donovan.† If two plates, one of copper, the other of zinc, be immersed in diluted nitric acid, but not in contact with each other, they both effervesce and dissolve, but if they be brought into contact, both effervesce, but the zinc alone suffers solution. The same results were obtained with all the metals when subjected to experiment, provided, however, that in each case, the two consisted of metals which had distinctly different attractive powers for oxygen. Mr. Donovan thinks he has proved that when metals are thus arranged in contact, the action of one is increased in proportion as that of the other is diminished; thus two wires of zinc were so placed in diluted nitric acid, as that one of them should be in contact with copper, while the other remained unconnected; both of them produced gas, but in the same space of time, the quantity evolved from the former was 8 or 10 times greater

* Nicholson's Journal, vol. xxviii. p. 112.

† Essay on Galvanism.

than that from the latter. From experiments like these this chemist has drawn the inference that the decompositions in the voltaic circuit are not the consequences of electrical action, but of the transfer of affinity from one metal to the other.

CCIII. Neutral salts are likewise susceptible of decomposition, and, in such cases, the acid is always separated at the positive, and the alkali at the negative surface of the battery. Thus if three cups of agate, or of gold, be connected with the apparatus, the middle being filled with solution of sulphate of potash, and the two others with pure water, and they be connected with each other by moistened amianthus, it will be found after a time, that the cup positively electrified will contain sulphuric acid, and the cup negatively electrified, potash, although no traces of either of these substances could be perceived in the water, previous to the experiment. If the two extreme cups be filled with infusion of red cabbage instead of water, the portion connected with the zinc end of the battery will become red, and that united with the copper end will be changed to a green; effects which are produced respectively by acids and alkalies. When the cups were formed of solid and insoluble saline compounds, such as gypsum, ponderous spar, and fluor spar, and were filled with pure water, it was found by Sir H. Davy, that after the experiment acid matter occupied the positive, and alkaline matter the negative cup; and as pure water was employed, these substances could have been produced only by the decomposition of the compound body in which the water was contained.

CCIV. So powerful is this apparent attraction of acids to the positive end, and of alkalies or bases to the negative pole, that in passing to the respective extremities of the battery, it was proved by Sir H. Davy, that they might be made to proceed through, without combining with substances, which in ordinary circumstances exert strong affinities. Thus when solution of sulphate of potash was put into the cup connected with the negative end, liquid ammonia in the middle cup, and

pure water in the cup in which was immersed the wire from the positive surface, on completing the circuit, and allowing the apparatus to remain in that state for some time, sulphuric acid was found in the water; when the order was inverted, the sulphate of potash being in the positive cup, acid in the middle, and water in the negative cup, the base of the salt or potash was discovered in the water. In the first instance, therefore, acid matter was transmitted through ammonia; and in the second, alkaline matter or potash passed through an acid without chemical union, notwithstanding the particles had freedom of motion, and are known to possess strong mutual affinities. By the same arrangements, acids and alkalis may be made to pass through coloured vegetable infusions without producing their characteristic effects.

CCV. The production of acid and alkaline matter may be observed even in pure water, provided it contain atmospheric air. At one time the source of the acid was mistaken, and it was announced with great confidence by Professor Pacchioni of Florence, that muriatic acid was formed, and that its elements were the same as those of water, but combined in different proportions. The mistake was pointed out both by Mr. Cruickshank and Sir H. Davy. It is not muriatic acid, but nitric acid which is produced, and it arises from the union of the oxygen disengaged at the positive wire with the azote of the atmospheric air contained in the water. The alkali is derived either from the decomposition of the glass vessel in which the experiment is made, in which case it is potash or soda, or from the union of the hydrogen evolved with the azote of the air combined with the water, forming ammonia. The disengagement of these matters may be seen by the use of a coloured vegetable solution. Introduce into a glass tube bent in the form of the letter V, a quantity of infusion of cabbage, pass through the cork of each extremity a wire of gold or platina below the surface of the liquid, but having their points sufficiently distant from each other to allow of the gases disengaged to rise one in each leg of the tube: on connecting it in

this state with a voltaic battery, the colour of the infusion positively electrified will be changed to a red, and that of the one negatively electrified will become green. On reversing the tube, the blue colour will first be restored in each, and then the one which was red will become green, and that which was green will be changed to a red.

CCVI. It was this view of the decomposing powers of voltaic electricity which led Sir Humphry Davy to attempt, by the same means, the decomposition of the fixed alkalies, potash and soda. The alkali was put into a tray of platina and connected with the two extremities of a powerful battery; oxygen was given off from the positive wire, but from the negative wire, instead of gas, bright metallic globules similar to mercury were produced, which immediately inflamed, and were projected through the air to a considerable distance, with bright scintillations. By using oil of naphtha, this great chemist preserved a sufficient quantity of these bases to demonstrate their properties. They are of a metallic nature; to the one he gave the name of Potassium, to the other that of Sodium.

CCVII. The analogy in properties which had always been remarked between the alkalies and the alkaline earths, naturally led to the belief of a similarity in chemical constitution. Accordingly, it was found by Mess. Pontin and Berzelius, and by Sir H. Davy, that when baryta, lime, strontita, or magnesia was formed into a paste with water, a globule of mercury being placed in a cavity made in the mass, and the globule was negatively electrified, the paste being positively electrified by a large battery, an amalgam was soon produced, which had the property of decomposing water, and of reproducing the earth. The bases of the alkaline earths, therefore, are analogous in nature to potassium and sodium, or are metallic, since they possess most of the physical characters of metals, and are capable of forming amalgama with mercury. This fact has since been more fully determined by the action of potassium upon these compounds.

Mercury, when negatively electrified in contact with some of the salts of ammonia, presents some highly important but anomalous phænomena, of which we shall speak hereafter.

CCVIII. It was first distinctly ascertained and announced by M. M. Fourcroy, Vauquelin, and Thenard, that the power of the Voltaic battery to ignite and burn the metals, and the power to give a shock and to produce chemical decomposition, are not coincident. The former appears to be dependent upon extent of surface, the latter upon the number of plates. A battery of 30 double plates, each of which shall be 12 inches in diameter, will have no greater effect upon the human body, nor upon chemical compounds, than a battery of the same number of plates only one inch in diameter, but it will render red-hot some length of platina wire, and burn metallic laminæ with facility. On the other hand, if the 30 large plates be divided so as to form a battery of 100 plates, the shock from it will be experienced in the elbows, and it will decompose water and other compounds with great rapidity, but it will not have the power of igniting wire, or at least, it will exist only in a very slight degree, nor will it burn thin leaves of the metals with the same ease and brilliancy as before. The maximum of chemical, and the maximum of electrical effect are not, therefore, coincident, and to account for this difference, it has been supposed, and perhaps justly, that the chemical effect is dependent upon the *intensity*; the electrical effect upon the *quantity* of electricity. Now the intensity is proportional to the extent of imperfect conductors through which the electrical influence is to be transmitted, and as the liquid in the cells of the battery is to be considered as possessing imperfectly conducting powers, the electrical energy requires to be accumulated to a certain degree, to overcome the resistance afforded to its extension. Hence the larger the number of plates, the greater is the amount of imperfect conductors through which the electricity is to be communicated, and the greater will be its effects upon the body, and upon chemical compounds when it is transmitted. But in the case

of a battery composed of a small number of large plates, the surface exposed produces a large quantity of electricity, but in consequence of the comparatively small extent of imperfect conductors through which it is to be transmitted, the resistance, and therefore the intensity are less, and the effect upon the human body is proportionally feeble.

The quantity in the small plates is as much or more than such imperfect conductors as water and the human body can carry off by a small surface; while better conductors can transmit the whole quantity afforded by the large plates, even when used in thin laminæ or wires. It has been found, that in a battery composed of large plates, three distinct circuits may be formed, in each of which voltaic phenomena will be produced, and all proceeding at the same time; these circuits being completed, the first by water, the second by the human body, and the third by charcoal.*

The power of igniting and melting the perfect conductors is dependent upon the quantity, and not upon the intensity of the electrical action, and hence, batteries with large plates operate more effectually in this way, than those with small plates. M. M. Gay Lussac and Thenard have inferred, that the power of chemical decomposition increases in the ratio of the cube root of the number of plates. Sir H. Davy on the other hand thinks that it is nearly as the squares of the number of plates, and that the power of *ignition*, for equal numbers of plates, seems to increase in a very high ratio with the increase of surface, probably higher than even the square.

All the effects, both chemical and electrical, of the voltaic apparatus may be obtained by the combination of size and number in the plates. Hence the battery at the Royal Institution, composed of 2000 double plates, not only exhibited intense power in decomposing bodies, but ignited, melted, and burnt the metals with astonishing rapidity, while the immense battery of Mr. Children, containing 20 triads, although it was remarkable for its power of fusion, yet produced no effect

* Davy's Elements, p. 84. Am. ed.

of consequence on the human body, nor upon chemical compounds. The best form of a battery for common purposes, according to Mr. Children, is that of Wedgewood's, already described, containing from 150 to 200 double plates 4 inches square.

We now come to the most abstruse and unsatisfactory part of this subject, the theory of the action of the Voltaic apparatus, and the mode in which it operates in producing chemical decomposition.

On this subject, no less than three hypotheses have been supported.

CCIX. In the early stages of Galvanism, Fabroni an Italian philosopher, referred all the effects then known to chemical action, the hypothesis being founded upon the phenomena which are observed in the experiment of Sultz. The chemical action is supposed to take place when two dissimilar metals are brought into contact. Mercury, tin, lead, and copper, when single, remain pure for a long time, but if they be combined, the alloy soon tarnishes, and oxidizement takes place. Hence the Etruscan inscriptions engraved on pure lead are still in perfect preservation, while the pontifical medals in the gallery of Florence, although of a much more recent date, are reduced almost to powder; and this effect is ascribed by Fabroni to the presence in the latter of tin, and perhaps of arsenic. If pieces of metals be put singly into water, they will preserve their polish for a long time, but if two masses of different natures be brought into contact under water, the polish will soon be destroyed, and oxide will be formed. The copper sheathings of vessels cannot be securely, nor permanently fastened by iron bolts, for the copper, iron, and sea-water, constitute a Galvanic arrangement, and the iron soon rusts. As metals have a tendency to combine with each other, this combination is prevented at common temperatures, by the strong aggregation of their particles. When brought into contact, the affinity which they exercise causes a diminution of cohesion, and thus, "though neither of them

separately may be able to attract oxygen from the air or from water, they may acquire that power by simple mechanical touch, as they pass to new combinations.*

Hence the experiment of Sultzzer was considered as nothing more than a combustion or chemical operation, and the taste and flash of light which were perceptible, might be attributed to a chemical action, to the transition of oxygen into a combination, to the formation of a new compound, or to the developement of a soluble or sapid taste. Some, if not all of the effects produced upon the bodies of animals, by the application of metallic coatings to the nerves and muscles, may be supposed to depend upon one or all of these causes. Fabroni, though he does pretend to exclude all electrical influence in the effects of Galvanism, yet denies that this principle has any thing to do with the experiment of Sultzzer; his explanation is this, that when zinc and silver are brought into contact at the extremity of the tongue, the metals undergo a slow combustion, or combine with oxygen, that caloric and light are disengaged with the rapidity of lightning, and that the sensation experienced in the tongue is the consequence of the chemical action which results in the formation of an oxide or a salt. It is therefore to these compounds, or to their elements, he attributes that mysterious stimulus which produces convulsive motions of the animal fibre in a great part of the phænomena of Galvanism. Very lately, Mr. Donovan has revived the hypothesis of Fabroni in an attempt to prove that the phænomena of the voltaic apparatus are not capable of being explained on the action of electricity; but that they are dependent upon chemical operations.† The hypothesis is, however, modified by the assumption that the cause of the action is the *transfer* of affinities from one metal to another in these arrangements. Mr. Donovan does not pretend to account for the mode of transfer, and it is impossible from any known laws of chemical action to give a satisfactory explanation of it.

* Nicholson's Journal, 4to p. 120.

† Essay on the Origin, &c. of Galvanism.

CCX. The hypothesis of Fabroni was proposed before the discovery of the effects of combined Galvanic arrangements. The pile of Volta having enabled philosophers to accumulate this power to an indefinite degree, the phænomena were more attentively studied, and the principle which gives activity to it was more patiently and successfully investigated. This investigation has terminated in the very general belief of the identity of the voltaic power and common electricity, and its effects have been detailed upon this belief in the preceding pages. Their actions are similar. Both, when transmitted through the human body, produce a shock; both affect the electrometer in the same way, and may be made to charge an electrical battery; both may be so managed as to ignite and burn the metals; and both will produce chemical decomposition. From the kind of shock, and the greater facility of charging a battery, voltaic electricity has been presumed to be of lower intensity, and to move with greater rapidity than common electricity. If these powers be identical, we must consider how the electrical excitation is produced in voltaic arrangements, and the answer to this question brings us to the two other hypotheses.

CCXI. The facts, that the simple contact of two dissimilar metals disturbs the electrical equilibrium, and that after their separation, one will be found positively, the other negatively electrified, were discovered by Mr. Bennet. They may be shown by insulating two plates, one of zinc, the other of copper, on glass, each being about 6 inches in diameter. These are alternately applied to and separated from each other, and after 15 or 20 contacts, either of them, on touching the condensing electrometer, will cause the leaves to diverge, the zinc with positive, the copper with negative electricity.

After Volta had erected the pile, he found that the two ends exhibited different states of electricity, the zinc always being positive, the copper always negative; and he explained the production of electricity on the facts above stated. The property by which two dissimilar metals by contact break the

electrical equilibrium, he called the *Electro-motive* power. Two dissimilar conductors in contact constitute the element of the pile, and to establish a current of electricity, for in this hypothesis electricity is considered as material, it is necessary that there should be three conductors ; which may be composed of one imperfect and two perfect conductors, or of one perfect and two imperfect conductors, or of three imperfect conductors. Let it be supposed then that a plate of copper is placed upon an insulated stand and a plate of zinc brought into contact ; a portion of electricity will pass from the copper to the zinc and the former will become negative, the latter positive ; if upon the plate of zinc be laid another plate of copper, this in its turn will also become negative by transferring a portion of electricity to the zinc ; two forces will thus operate in opposite directions, and the consequence would be that were a pile to be reared in this way, it would exhibit no electrical power. But if instead of the second plate of copper, we substitute a disc of moistened cloth, then the condition, stated by Volta to be necessary to the current of electricity, will have been fulfilled, for the cloth possessing little or no electro-motive power, will act only as a conductor, and if a plate of copper be placed on it, the electricity will be conducted from the zinc, through the moistened cloth to the second copper plate, which acquires the state of the first zinc plate ; and the latter again becomes positive at the expense of the first copper plate which becomes more strongly negative. Hence, the greater the number of triads of copper, zinc, and moistened cloth, the more negative will be the copper, and the more positive the zinc, the power increasing toward each extremity, from the middle of the pile, which is neutral. Now if in this state two wires connected with the zinc and copper ends of the pile be brought into contact, the electricity will pass from the former to the latter, and a circuit will thus be established. If the human body be interposed, it will receive a shock proportional to the intensity, which is dependent upon

the amount of imperfectly conducting liquids through which the electricity passes.

CCXII. To give a more precise view of the mode in which the electrical energy is exalted in the pile, let us represent the quantities of electricity in the plates by numbers, as has been done by M. Biot and M. Thenard. When a plate of zinc is brought into contact with a plate of copper, the difference in their electrical states on separation is the same, the zinc will be found as highly positive, as the copper is highly negative, and if the former be represented by $Z + \frac{1}{2}$, the latter will be represented by $C - \frac{1}{2}$. Suppose, then, that upon an insulated stand S,* a disc of copper C be placed, and upon it a disc of zinc Z, the electricities of which are respectively $-\frac{1}{2}$ and $+\frac{1}{2}$; the zinc plate is covered with a disc of cloth H, moistened with water which answers merely as a conductor, and upon this a second plate of copper, C'. Now as the zinc plate Z contains $+\frac{1}{2}$ of electricity, it ought to yield one half of it, through the medium of the cloth, to the second copper disc C', in which case its electrical state would be equal to $\frac{1}{4}$. But then the electricity of C would be $-\frac{1}{2}$, which state would not correspond with facts, for the difference between the two electrical states should always be equal to unity, and the sum of the electricities of the three discs to 0. It follows, then, that the electricity of C must be represented by $-\frac{2}{3}$, and that of the disc Z by $\frac{1}{3}$. Suppose another plate of zinc Z' be placed upon the copper plate C', the former must contain an unity more of electricity than the latter, C' will contain as much more than Z, and Z an unity more than the first plate C; the electric state of C therefore will be equal to -1 ; that of Z to 0; that of C' 0; and that of Z' $+1$. The electrical states therefore of the different plates may be easily found, because on this hypothesis, the difference between these states in two contiguous plates of copper and zinc is always coincident, and one is positive in proportion as the other is negative. If there be an even number of plates, the electrical state of C

* Plate v. fig. 6.

may be discovered by dividing the number by 4, and prefixing to the quotient the negative sign —. Suppose the plates amount to 16, then the electricity of C will be represented by — 4, and the electrical state of the whole series will be — 4, — 3, — 3, — 2, — 2, — 1, — 1, 0, 0, + 1, + 1, + 2, + 2, + 3, + 3, + 4. It appears, therefore, that the opposite extremities are differently but equally electrified, that any two discs, the one in the superior, the other in the inferior half, but both at equal distances from their respective ends, are likewise equally electrified, and that there are two in the middle which are neutral. If there should be an odd number of discs, the electrical state of C may be found by taking the half of the number diminished by unity, and the half of the number augmented by unity, multiplying them into each other and dividing the product by the whole number of plates, the sign — being attached to the quotient. Thus suppose it be wished to find the difference in the electrical states of the extremities of a pile of 5 discs, then $3 \times 2 \div 5 = \frac{6}{5}$, and, consequently, the states of the four other discs will be respectively $-\frac{1}{5}, -\frac{1}{5}, +\frac{4}{5}, +\frac{4}{5}$.

Such are the circumstances which would take place, supposing the copper plate C to be placed upon an insulated stand. But it is obvious that the case would be different if it were in communication with the ground; it would constantly remain at zero, and the others would necessarily be in the state of + 1, + 1, + 2, + 2, &c; for in consequence of being connected with the common reservoir, as the earth has been termed, electricity would be furnished to it as rapidly as it was transmitted to the plates above, and it must continue at 0. If the superior zinc plate Z^v , were brought into connexion with the earth, its electricity would be represented by 0, and all the plates below it by — 1, — 1, — 2, — 2, — 3, — 3, &c. If the pieces of moistened cloth were not present, the electricity of each pair of the pile would be $+\frac{1}{2}, -\frac{1}{2}$; and when connected with the ground, if the copper, it must be 0, and the zinc + 1, if the zinc, it would be represented by 0, and

the copper by — 1.* The electrical states of the plates have been here demonstrated in the pile ; but the above observations are equally applicable to the other forms of the voltaic apparatus. In the common troughs the liquid contained in the cells has the same relation to the compound plates, as the moistened discs of cloth in the pile of Volta.

In both cases the effects of the interposed fluid are supposed to depend altogether upon its conducting power ; saline solutions are better conductors of electricity than water, solution of potash is superior to the saline solutions. and diluted acids possess this property in a higher degree than liquid potash, and the last are known to act with most energy in voltaic combinations.

CCXIII. The hypothesis of Volta, so far as it relates to the active principle of the battery, was soon after its enunciation received by the British chemists, but the experiments of Col. Haldane, Dr. Wollaston, Sir H. Davy and others, led to the belief that the chemical action of the interposed media upon the plates was necessary to the evolution of electricity. The third hypothesis, therefore, which combines in some measure the peculiar opinions of Fabroni and of Volta, was adopted. It was first stated by Dr. Wollaston in the three following propositions. 1. That the influence on the pile which produces Galvanic phænomena, is identical with the electric fluid. 2. That this electricity is generated by the oxidation of one of the metals. 3. That the production of common electricity is owing to the same cause, namely, the oxidation of the amalgam. These propositions were supported by experiments, and in conclusion the inference was drawn, that electricity, great in quantity but at a low intensity, constituted what is commonly called Galvanism.†

CCXIV. When an active liquid, such for example as diluted acid, is interposed between the compound plates, the action in all cases appears to be limited to the one which has

* Thenard. *Traité de Chimie*, t. i. p. 97. Biot. *Traité de Physique Experimentale*, t. ii. p. 478.

† *Phil. Trans.* for 1801.

the strongest attraction for oxygen; hence it is the surface of the zinc which suffers the change. The *current* of electricity on this hypothesis may be supposed to be determined in the following way. Suppose an arrangement in two triads to be made of copper, zinc, diluted acid; copper, zinc, acid; the surface of the zinc becomes oxidized, the electricity is evolved, and from the imperfectly conducting power of the liquid is for a time confined to the surface of the zinc, the substance of the plate is rendered negative, which state is communicated to the copper plate in contact; when the electricity is sufficiently accumulated, it overcomes the resistance and is conducted through the liquid to the next copper plate, thence to the surface of the zinc, and thus the current is formed from the copper to the zinc. Hence, according to Dr. Bostock, although one end of the battery becomes highly positive, and disposed to communicate a portion of its redundant electricity to the other end, yet this end is to be considered as only relatively negative, and there is no part of the apparatus in a neutral state. The essence of the operation consists in the oxidizement of one of the metals, consequently there is no tendency in any part of the apparatus to restore the equilibrium of the electric fluid, and its only effect is to increase the electricity of one end of the apparatus. The chemical hypothesis supposes an actual evolution of electricity in consequence of the chemical change on the surface of the most oxidable metal, by which its capacity to retain this principle is diminished.*

This hypothesis differs from that of Volta in ascribing the electrical excitation entirely to the chemical action on the plates.

CCXV. It seems to be a fact, that in general the chemical powers of the battery are proportional to the action between the metals and the interposed media; for it appears, 1. That the fluids act only upon one of the metals. 2. That the surface of only one of them is oxidized with a certain de-

* Annals of Philosophy, vol. iii. p. 36.

gree of rapidity. 3. That the oxide is removed so, as to expose a fresh surface to the fluid. If acids be employed, those are the best which dissolve the oxide, or if neutral salts, those which form triple salts with the oxide which is produced. 4. That the voltaic battery charged with pure water, will exhibit no action *in vacuo*, nor in airs destitute of oxygen; but may be slightly excited in atmospheric air and more strongly in oxygen gas; that if common salt be added to the water, the effect will be increased; if the solution be acidulated with muriatic acid, it will be still more evident; and that if diluted nitric acid be substituted for the acid solution, it will be energetically excited.*

Mr. De Luc has shown in his analysis of the pile, that the conditions necessary to the production of chemical effects are the successive associations of zinc and silver or copper with a liquid and the oxidizement of the zinc.

CCXVI. The action of the Electric column of De Luc, which has perhaps improperly received the name of *dry pile*, has not yet been sufficiently investigated. It has been supposed to prove the evolution of electricity by the simple contact of dissimilar metals, and to favour the idea that oxidizement of the metals has no influence in commencing or continuing its action. But if the small quantity of moisture contained in the paper be not active, as there is reason to believe it is from the fact that the pile does not operate when *perfectly* dry, it appears by experiment that in one instance at least, the air in the tube, after its electrical excitation had ceased, was found to have lost nineteen per cent. of oxygen; and that it was immediately rendered active by the cautious introduction of oxygen gas.† This kind of pile, however, is incapable of producing chemical decomposition; for while Mr. Singer's 20,000 groups were able to charge an electrical battery, to give a shock, and to cause pith-balls to diverge, they occasioned no sensible change in water when in-

* Annals of Philosophy, vol. iii p. 36.

† Journal of Science and the Arts, vol. ii. p. 161.

troduced into the circuit. This absence of chemical power may perhaps be explained upon the supposition, that the electricity in this apparatus is in a low state of intensity. The electrical and chemical effects of the voltaic battery are not coincident, and the connexion which subsists between them has not yet been clearly developed. Mr. De Luc, in his analysis of the pile, drew the conclusion that they are not produced by the same cause. By varying the usual mode of constructing the apparatus and ascertaining its powers in its different modifications, he inferred that certain associations of metals produce the circulation of the electric fluid, without occasioning the shock or chemical effects; and that for the production of the two latter effects, a fluid must constitute a part of the pile, which is capable of oxidizing one of the metals.

CCXVII. The arguments in favour of the production of electricity in the battery by chemical action alone, are many and powerful. But on the other hand, the fact is generally acknowledged that the contact of two dissimilar metals places them, with regard to each other, in the relation of positive and negative. This being admitted, the explanation of the *modus operandi* of the elements of the battery will depend upon the view which is taken of the influence of the plates upon each other, and upon the fluid with which they are in contact.

In adopting the hypothesis of Franklin of one fluid, it may be supposed that when two plates, the one of zinc and the other of copper are brought into contact, the electro-motive power as it has been called by Volta is exerted, a portion of the natural electricity of the copper passes into the zinc plate and through its substance to the opposite surface; this surface then becomes positively electrified, and the substance of the zinc as well as the copper plate negatively electrified. By the action of the surface of the zinc plate upon the contiguous fluid, it becomes oxidized, or particles are constantly removing by which it is rendered no longer capable of re-

taining the electricity ; this principle then, when sufficiently accumulated to overcome the resistance afforded by the imperfectly conducting liquid, passes from the surface acted upon through the fluid to the next copper plate, thence to the zinc and to its surface, where it is again set in motion by the chemical action. As the oxide, which is formed at the surface of the zinc plate, is removed by the liquid in contact, that surface is again adapted to the reception of the electricity. The electro-motive power of the metals and the chemical powers are thus successively exercised in imperceptible periods of time, and the evolution of the electricity continues so long as the surface of the zinc is acted upon by the liquid in contact. In this hypothesis, then, it is concluded, 1. That the tension or equilibrium of electricity in the two metals is disturbed by contact ; and 2. That the chemical action of a liquid is required for the evolution, and its conducting power for the transmission of the electricity. It will be seen, however, when we come to the subject of the decompositions effected in the circuit of the voltaic battery, that this mode of explanation is encumbered with difficulties which cannot be easily surmounted ; that a less complicated action will produce the same results, if we believe in the existence of a vitreous and a resinous fluid ; and that the phænomena may perhaps be explained in a still more simple mode, if electricity be considered with Sir H. Davy as an exhibition of the inherently attractive and repellent powers of matter.

CCXVIII. In the hypothesis of Dufay, which owes its present form to the researches of M. M. Coulomb, Poisson, and Biot, the natural electricity, or at least a portion of it contained in the two plates of copper and zinc, must be supposed to be decomposed when they are brought into contact ; the vitreous electricity will be accumulated upon the surface of the zinc, and the resinous upon the surface of the copper. Supposing then the two plates to be upon an insulated stand, and the copper undermost, the amount of the vitreous electricity may be considered as $+\frac{1}{2}$, and that of the resinous as $-\frac{1}{2}$.

(CXCII.) The moistened cloth is applied to the zinc, and over it a second plate of copper; to this plate, the zinc yields $+\frac{1}{3}$ of its electricity, a further decomposition of the natural electricity of the first pair must take place until the first copper plate becomes $-\frac{2}{3}$; if a second plate of zinc be placed upon the second plate of copper, the electricities of the series will be as follows, second zinc plate $+1$, second copper plate 0 , first zinc plate 0 , and first copper disc -1 . Hence the more of vitreous electricity there is accumulated on the upper zinc plate, the more will there be of resinous electricity upon the lower copper plate; the amount in each series diminishing as it approaches the middle, where the intensity is 0 . The amount of the separate electricities therefore increases in an arithmetical ratio with the number of the plates. Now when the circuit is completed, or when the opposite ends of a pile or battery are connected by a conductor of electricity, the two fluids, the vitreous from the zinc or positive pole, and the resinous from the copper or negative pole, instantly unite and form the natural or compound electric fluid. During this communication, no excitation will be apparent, unless the quantity of the electricities be greater than can be at once transmitted by the medium of connexion. If instead of being insulated, the copper plate of the battery be in communication with the ground, its electrical state will be 0 , and all the elements of the apparatus above it will be positive. If the two poles be then brought into connexion by a perfect conductor, the zinc being highly positive, while the copper is neutral, the former will afford its electricity to the latter, and receive it from the next pair, this pair in its turn will receive electricity from the one below, and thus a current will be established from the positive to the negative pole, and from the negative through the battery, to the positive pole; and as it passes more quickly through the perfect conductor from the zinc to the copper, than it does through the imperfectly conducting fluids in the apparatus from the copper to the zinc, the two

poles will be in the same state of tension.* When a compound body, which has imperfectly conducting powers, is introduced into, or made a part of the circuit, it is decomposed, its elements are separated and found at different poles, the result depending upon the nature of the compound. The decompositions are produced, according to this hypothesis, by the operation of laws which were discovered by Professor Berzelius and Sir H. Davy, and the details of which will lead us into the consideration of the most interesting of the theories that have been proposed upon this subject.

CCXIX. It has been already stated, (CCH—IV.) that when compounds are decomposed by the voltaic apparatus, some substances are separated at the positive, and others at the negative pole. The generalization of facts of this kind was first made by Mess. Hisinger and Berzelius. They found that when compounds were electrified in the circuit of the battery, oxygen and acids always appeared at the positive pole, and combustibles, earths, alkalies, and oxides at the negative pole. On investigating this subject, Berzelius was led to the hypothesis that the cause of chemical affinity may be found in the electrical states of the atoms of different bodies; that these atoms possess with regard to each other polarities, and those which are attracted to the positive pole of the battery may be called *electro-negative*, and those which are separated at the negative pole *electro-positive*. Of the former, there is but one body, and that is oxygen; but compounds, in which oxygen predominates, such as the acids, are also *electro-negative*. There are some substances which are *electro-positive* in relation to one set of bodies, and *electro-negative* with regard to others. All the combustible bodies and their combinations which are collected around the negative pole, are *electro-positive*. It follows from this view that the more the electrical states of two bodies are opposed to each other, the stronger will be their tendency to chemical combination; and as in actions of this kind, heat and light

* Thenard. *Traité de Chimie*, t. i. p. 104.

are often perceptible, the phenomena may be supposed to depend upon the discharge between, and the annihilation of the two electricities.*

CCXX. The subjects which gave rise to the hypothesis of Berzelius were nearly at the same time investigated by Sir Humphry Davy, but the results of his experiments induced him to view the cause of the actions in a different light. It was found by this illustrious chemist, that oxygen, chlorine, and the acids were attracted to the positive, and combustible bases, alkalis, earths and oxides, to the negative pole; that these classes of bodies were therefore in electrical states opposite to those of the poles, at which they were separated; that oxygen, for example, was attracted by the positive, and repelled by the negative pole, and that when thus brought into contact with one of them the electrical equilibrium was restored. Hence it was to be presumed, that different bodies possess naturally or inherently different electrical energies, and that the cause of chemical affinity may be identical with electricity, this cause in the one case operating upon the particles, and in the other upon masses of matter. "Most of the substances, which act distinctly upon each other electrically, are such as act chemically when their particles have freedom of motion; this is the case with sulphur and the metals, with acid and alkaline substances; and the relations of bodies are uniform; those that have the highest attractive powers being in the relation of positive in arrangements in which chemical changes can go on." Many facts are brought forward to substantiate this doctrine. All the acid crystals when touched by a metal render it positive; and oxalic acid, on coming into contact with dry quicklime, exhibits electrical powers, the acid being positive, and the lime negative. It appears also that bodies which previous to their union show electrical effects, lose this power after combination. Acids which are negative with respect to alkalis, metals and earths are separated from these bodies in the voltaic circuit at the

* Nicholson's Journal, vol. xxxiv. p. 153.

positive surface, and the bases at the negative surface; and such is the attractive power of these surfaces for the respective bodies that acids may be transmitted through alkaline solutions, and alkalies through acid solutions to the surfaces or poles where they have their points of rest.

CCXXI. The connexion, existing between electrical phenomena and chemical changes, is likewise evident in the general phenomena of the voltaic battery. The most powerful combinations are formed by substances that act chemically with most energy upon each other; and such substances, as undergo no chemical change in the combination, exhibit no electrical powers. Electrical effects are shown by the same bodies when acting as masses, which produce chemical phenomena when acting by their particles; it is not therefore improbable that the primary cause may be the same, and that the same arrangements of matter which place bodies in the relations of positive and negative, i. e. which render them attractive of each other electrically, and capable of communicating attractive powers to other matter, may likewise render their particles attractive, and enable them to combine when they have full freedom of motion.*

CCXXII. Such is the hypothesis of this distinguished chemist. It has been introduced here in order that the theory of the voltaic apparatus, in which these principles are applied, may be more perfectly comprehended. This theory is as follows.—Each plate of zinc is made positive, and each plate of copper negative by contact; and all the plates are so arranged with respect to each other, as to have their electricities exalted by induction; so that each polar arrangement heightens the electricity of every other polar arrangement; and the accumulation of power increases with the series. When the battery is connected in a circle, the effects are demonstrated by its constant exhibition of chemical agencies, and the power exists so long as there is any menstruum to decompose. It seems absolutely necessary for the exhibition of the powers of

* Elements of Chemical Philosophy, Part I. Article *Electricity*.

the voltaic apparatus, that the fluid between the plates should be susceptible of chemical change, which appears to be connected with the property of double polarity, of being rendered positive at one surface, and negative at the other ; and the constant operation of the battery may very probably depend upon this polarity in water, and the power to evolve oxygen and hydrogen ; and acids or saline bodies may increase the action by affording elements which possess opposite electricities to each other when mutually excited ; the action of the chemical menstruum exposes continually new surfaces of the metals, and the electrical equilibrium may be conceived to be alternately destroyed and restored, the changes taking place in imperceptible portions of time.

CCXXIII. In this theory then, Sir Humphry infers with Volta, that dissimilar metals by contact break the electrical equilibrium, and with the British chemists that chemical action is necessary to produce the phænomena of the battery ; but he differs from both in ascribing the effects to the exertion of inherently attractive and repellent powers in matter, and to the alternate action and neutralization of these powers. Suppose then two polar arrangements, as they have been called, to be formed of copper, zinc, diluted acid ; copper, zinc, acid. By contact, the first copper plate becomes negative, and the first zinc plate positive ; the second copper plate, being opposite to the first plate of zinc, becomes more highly negative, and the second plate of zinc more highly positive by induction. When the circuit is completed by a conductor of electricity, the polar arrangement is communicated to the liquid, and the oxygen of the water being naturally negative will be attracted to the zinc, while the hydrogen being naturally positive will be attracted to the copper, and the electrical tension or equilibrium will be restored ; but only for a moment, for the oxygen combines with the zinc and is removed, a fresh surface of the metal is again exposed, and the contact of the metals again occasions the exhibition of electrical energies. These alternate actions

taking place in imperceptible portions of time, the energy of the battery will appear so long as the plates and the liquid mutually operate upon each other. If diluted nitric acid be employed, its elements will be partially separated, oxygen will be attracted to the positive pole, and the remaining compound nitric oxide, in which the electricity of the base or azote predominates, will pass to the negative. If muriatic acid be substituted, it is probable that the water alone will suffer the change; but if the acid should be decomposed, chlorine will be attracted to the zinc, and hydrogen to the copper. If the liquid consist of solution of common salt, chlorine or muriatic acid will pass to the former and soda to the latter.

CCXXIV. This view of the actions which take place in voltaic combinations, and of their cause is strengthened by the facts discovered by Ehrman. He found that the insulated flames of wax, oil, spirit of wine and hydrogen gas conducted only positive electricity, while dry soap and the flame of phosphorus transmitted only negative electricity. Such bodies were therefore named *Unipolar*. Mr. Cuthbertson also, on transmitting electric sparks through the flame of a candle, placed between two electrified surfaces, found the negative surface most heated, and this experiment has been brought forward as one of the proofs that a current of electricity actually passes from one surface to the other. The fine experiments of Mr. Brande, however, have demonstrated that the effects in such cases are connected with the chemical nature of the bodies employed, and that the phænomena may be explained according to the known laws of electrical attraction. By a simple but ingenious apparatus, he has shown, that the flames of olefiant gas, of hydrogen, and arsenicated hydrogen gases, of sulphuret of carbon, of potassium, flowers of benzoin, and camphor, are uniformly attracted towards the negative pole; while sulphurous acid, acid vapour of phosphorus, carbonic acid, vapour of phosphoric acid, muriatic acid gas, nitrous acid gas, vapour of benzoic acid, are always attracted to the

positive pole. These facts have been happily generalized by Mr. Brande, and the conclusion is, that the same bodies which are attracted by the positive, and repelled by the negative poles of the battery, are likewise attracted and repelled by the corresponding surfaces of the common electrical machine. In the first set of experiments, the combustible substance predominating, the products were electro-positive, and of course were attracted to the negative pole; in the second case, the results being acids or acid matter, they were electro-negative and passed to the positive pole. Regarding these experiments, says Mr. Brande, as connected with electro-chemical theory, they appear to furnish a more evident proof than has hitherto been offered of the inherent electrical states of matter, which are decidedly exhibited by the attractions and repulsions between the opposite poles; and amply demonstrate the identity in chemical powers of common and voltaic electricity.

CCXXV. We shall now be able to understand the mode in which compound bodies are inferred in these theories to be decomposed in the voltaic circuit, and to illustrate the actions which take place, we shall adduce the example of water as being the most simple. When wires of gold or of platina are connected respectively with the different poles of the apparatus in activity, and the extremities are brought near each other in a vessel of water, bubbles of gas will be seen to rise from both, and it has been sufficiently demonstrated not only that oxygen proceeds from the positive wire, and hydrogen from the negative wire, but likewise that they are evolved in the precise proportions required for the constitution of water. There can be no doubt, therefore, that in such cases the liquid is actually decomposed and resolved into its elements.

Upon the hypothesis of Sir H. Davy, the process is very simple. When water constitutes a part of the voltaic circuit, the particles of the liquid in the line between the wires become polarised, the particles of oxygen being inherently negative, are attracted by the positive, and repelled by the negative

pole, while those of hydrogen, which are naturally positive, will be attracted by the negative, and repelled by the positive pole ; two currents therefore will be established, one of hydrogen from the positive to the negative wire, and another of oxygen from the negative to the positive wire. All the particles of water which are polarized will thus suffer decomposition, but a particle neither of oxygen nor of hydrogen can be disengaged until it arrive at its respective pole ; and as two currents are established in opposite directions, and at imperceptible distances, the particles of oxygen and hydrogen, as they pass to the opposite poles, slide over the surfaces of each other, so that in fact there is no permanent decomposition excepting in one particle of water at each of the wires. The phænomena which are inferred to take place in this experiment may be represented by fig. 7, plate v.* In this figure the two wires are supposed to be immersed in water, between which are placed four polarized particles of liquid ; the elements of three of them are still in contact, and the current of oxygen furnishes one particle to the positive pole, while the current of hydrogen gives another to the negative pole. As the atoms of water are decomposed, others become polarized, and thus the decomposition may be kept up until the battery cease to act. When the particles of oxygen and hydrogen have reached their respective poles, their electrical states are neutralized, and they leave the wires in the form of elastic fluids. Precisely the same view may be taken of the decomposition of acids, saline matter, &c. premising that their particles have freedom of motion, and are thus enabled to assume a polarized state.

The decomposition of water, &c. in the hypothesis of two electric fluids is explained in the same way, excepting that those elements which are attracted to the positive surface are inferred to possess resinous electricity, and those which pass to the negative, vitreous electricity. When arrived there the resinous fluid of oxygen combines with the vitreous fluid of

* From Mr. Donovan's History of Galvanism.

the positive pole, and the vitreous fluid of the hydrogen unites with resinous electricity of the negative pole, the electric states in both are neutralized, and they are disengaged.

CCXXVI. Upon the hypothesis that the phænomena of electricity depend upon one fluid, and that this fluid in voltaic arrangements passes from the positive to the negative surface when the circuit is completed, the mode of action must be more complicated. Supposing the arrangement with water the same as before, the electric fluid will pass from the positive wire into the water, and decompose the contiguous particle of that liquid; the oxygen will be evolved in the form of gas, but the hydrogen must pass through the whole space between the wires, in an invisible manner, to arrive at the negative pole. How is this transfer produced? Is it the effect of a mutual attraction between the hydrogen and the wire negatively electrified? Or does it result from some agency of the electric fluid in its passage through the liquid? The fact of an attraction existing between hydrogen and the negative pole is not admitted in this hypothesis, and hence the phænomenon has been explained in conformity with the opinion of Dr. Bostock. This ingenious chemist takes for granted, that an union ensues between the electric fluid and the hydrogen, in this state it passes through the water, but so soon as it reaches the negative wire, the electricity enters into it, the compound is destroyed, and the hydrogen assumes the gaseous state. This hypothesis is adequate to the explanation of the facts, but it is altogether gratuitous, and will appear to many improbable. In assuming it as true, the propositions must be granted, 1. That electricity is matter. 2. That it has an affinity for hydrogen. 3. That this combination is necessary for its transmission from one surface to the other when water constitutes a part of the voltaic circuit. These data are arbitrary; and they are assumed merely for the convenience of explaining the phænomena.

CCXXVII. In comparing the two principal theories which have been proposed to account for the effects of voltaic ar-

rangements, the one which has been adopted by the British chemists appears to be superior to that of Volta, which has been embraced by most of the European philosophers. In the theory of Volta, none of the phænomena are attributed to the chemical action of the interposed media. The liquids which are introduced into the series are supposed to answer no other purpose than to conduct the electricity from the zinc plates, on which it is accumulated in consequence of simple contact with the plates of copper. Hence it follows, that those fluids which possess this conducting property in the greatest degree, must act with the greatest effect in exalting the energies of the battery. There are some facts which favour this opinion; but there are others, and they are not only more numerous, but also more weighty, which warrant the conclusion, that the chemical action of the liquids upon the plates is essential to the continued exhibition of the powers in these arrangements, or at least that it is necessary to the production of the phænomena of decomposition.

CCXXVIII. But in examining the merits of the two British theories, the preference is in favour of Sir H. Davy's. The opinion of the existence of one electrical fluid involves difficulties which are not easily surmounted, and when applied to the facts connected with the voltaic apparatus, and particularly to those relating to decompositions, it fails unless we assent to propositions which are not susceptible of proof and reason upon data which are purely speculative and hypothetical.

The phænomena of common electricity arise from attractions and repulsions of masses of matter at sensible distances; it was therefore probable *à priori*, that the same actions should in certain circumstances take place between the particles of different bodies. So far as the subject has been experimentally investigated, the results appear favourable to this conclusion, and it seems merely an expression of facts to say that the particles of matter as well as the masses which they compose, possess these powers, or have inherent electrical ener-

gies. The hypothesis of the French philosophers, which refers all electrical action to the mutual operation of two fluids, has been shown by the researches of M. M. Coulomb, Poisson, and Biot, to be more extensively applicable to these phænomena, and more conformable to fact, than the principles of the Franklinian theory ; and yet the facts which they describe, and the laws which they have developed, might have been conveyed to the student with the same facility had the doctrine of two fluids been omitted. Indeed, the existence of a specific electrical matter has never been demonstrated by decisive experiments. The facts which have been adduced to prove the course of this matter are all more or less equivocal, and the phænomena displayed by unipolar bodies seem to be decidedly adverse to the opinion. The French philosophers, notwithstanding they have employed their profound mathematical knowledge in demonstrating the principles of their hypothesis, yet candidly acknowledge that it does not proceed beyond probability, that the foundation itself is speculative, and that the language which they have used is intended merely to facilitate the communication of facts. Our illustrious countryman, Dr. Franklin, appears to have advanced his opinions upon the same grounds, and both hypotheses have been submitted to the investigations of others with a true philosophical spirit.

M. Berthollet has remarked that in making an experiment, it is necessary to have some object in view, and to be guided by some hypothesis ;* but it is equally true, that premature induction has sometimes been the cause of serious injury to science, for the results of experiments are apt to be viewed in the light most favourable to the hypothesis previously adopted. Chemistry, as a science, remained stationary from the time that Stahl promulgated the doctrine of phlogiston, until the age of Cavendish, Priestley, and Lavoisier. Yet it is not improbable, that if that celebrated chemist had possessed himself of all which was really important, and had been publish-

* Chemical Statics. *Introduction.*

ed upon this branch of knowledge, he might have collected from the writings of Rey and of Mayow, facts and speculations, which, when moulded by his genius and experience, would have placed upon his head the wreath that has since adorned the brow of Lavoisier.

CCXXIX. The facts which have been developed by the researches made into the subject of voltaic electricity, are perhaps more curious than any others within the range of chemical philosophy. But they derive their greatest interest from their obvious tendency to establish the general principle that the ultimate causes of electrical and chemical phenomena are identical. From what has been already stated, this conclusion does not appear very improbable, and it receives additional support from the circumstance that the production of heat and light in many rapid actions, and particularly in the common and familiar processes of combustion, cannot be satisfactorily explained upon the acknowledged laws of chemical science. Electrical action, when of any intensity, is always accompanied with these appearances, and facts seem to warrant the conclusion, that they do not, in most cases, arise from changes which take place in the bodies subjected to this influence, but rather from the electricity itself. If, therefore, Caloric, Light and Electricity be distinct and independent fluids, they must be here associated or combined; and in this view, the constitution of the last, as we shall endeavour to show in the succeeding chapter, will be exceedingly complex.

At present, the idea that electricity and chemical affinity depend upon the same cause, is to be considered as an hypothesis which has been proposed rather to invite investigation, than to constitute one of the doctrines of the science. The subject is still novel and much research will be required before it can be either established, or overturned. The laws of crystallization, of definite proportions, and of the electrical polarities of bodies, says Sir Humphry Davy, seem to be intimately related; and the complete illustration of their connexion, will probably constitute the mature age of chemistry.

CHAPTER V.

OF THE NATURE AND MUTUAL RELATIONS OF CALORIC,
LIGHT AND ELECTRICITY.

CCXXX. THE precise nature of the cause, which produces in us the sensation of heat, has never been discovered. We have not yet arrived at the essence of a single ponderable element; much less can we hope to ascertain the nature of the subtle principle which eludes all attempts to confine and examine it. Hence it is not surprising that philosophers have differed in opinion upon this subject; nor that while some believe in the material existence of Caloric, others infer that it is a quality of matter or consists in motion.

CCXXXI. It has been said in favour of the hypothesis, that Caloric is matter, 1. That the volume of a body is proportional to its temperature; if the latter be increased, the former will be augmented and conversely, that when the heat is reduced, the bulk will be diminished. Hence, as there appears to be no limits to the expansion on the one hand, nor to the contraction on the other, supposing the form of the body to be permanent, it has been inferred that its particles are not in contact; and as in the first case, nothing has been applied, nor in the latter withdrawn, but caloric; the conclusion has been adopted that the separation, or approximation of the particles, must be owing to the ingress or egress of an attenuated matter.

2. When a solid is converted into a liquid by solution, the temperature falls, and it again rises when the liquid is changed to a solid. The same phenomena are observed in the passage of dense into rarer bodies, and of rare into denser bodies. In the first case, it is apparent that the particles are separated, and in the second, that they are brought nearer to each other, and as expansion is produced by heat, it is supposed that liquids and elastic fluids owe their forms to the caloric which they contain; but as their temperatures are

not higher than those of the bodies from which they are formed, the caloric must be combined with their particles, and exist as specific or latent caloric. Bodies during their condensation, do not all produce the same rise of temperature ; it is greater in some than in others, and hence it has been inferred, that different kinds of matter have different attractive powers for the matter of caloric. The heat given out by some bodies may be communicated to others, from which it may be again recovered, and the most obvious conclusion is, that caloric is material.

3. Hot bodies have been proved by Dr. Franklin, to cool in the vacuum of an air-pump, and by Pictet and Count Rumford even in a torricellian vacuum. In both of these, there existed without doubt an elastic fluid, but the rapidity of cooling was greater than could be supposed to have taken place by slow communication, or conduction. The caloric, therefore, must have passed off by radiation, which implies the emanation, and the mutual repellancy of calorific particles. Radiant caloric exists in the solar rays, and there is the same evidence for supposing that its phænomena are produced by the action of a specific and subtle fluid, as for believing in the materiality of light. But if solar heat be matter, the radiant caloric of terrestrial bodies must likewise be matter.

4. If caloric exist as an highly attenuated fluid, the particles of which repel each other, while they are attracted by those of other bodies, and if the atoms of matter be not in contact, they must be surrounded by, or the spaces between them filled with this calorific matter, and when they are brought nearer to each other, the caloric must be pressed out and rendered sensible. Such, in fact, is supposed to be the effect of strong percussion, or compression.

5. During friction, the particles of the bodies suffer a momentary compression, and the caloric is pressed out, but when they resume their original situation, caloric flows in from the mass, and this in its turn is supplied by the bodies, and the

earth with which they are connected. By repeating the operation, caloric may thus be accumulated to a great degree upon the surfaces in contact, and from them be communicated to other bodies. This shows a relation in one property at least between caloric and electricity.

6. The imponderability of the cause of heat is not an argument of much force against its material nature, for it would be difficult, by any instruments which we can command, to ascertain the gravity of a body, which should be as much lighter than hydrogen, as hydrogen is lighter than platinum.

The strongest arguments in favour of this hypothesis are derived from the phenomena of radiation, and from the facts that increase of temperature results from condensation, and a diminution of heat from rarefaction.

CCXXXII. Caloric then in this hypothesis is considered as an highly attenuated, elastic, and imponderable fluid, composed of particles which are mutually repellent, but attractive of those of other matter. Hence its tendency is to diffuse itself uniformly, and the equilibrium is effected by the conducting and radiating powers of bodies. It is contained in all forms of matter in quantities depending upon their mutual attractions, and each particle is supposed to be surrounded by this agent in the form of a calorific atmosphere, which gives it a repulsive energy. The distance to which the particles will be mutually repelled is proportional to the amount of this atmosphere. In solids, cohesion is superior to calorific repulsion; in liquids, the former power is diminished, but it still acts, and although the particles have freedom of motion, they are yet in apparent contact; in elastic fluids, the repulsive becomes greater than the attractive force, the particles recede and the distance to which they may be repelled is indefinite. The forms of bodies then result from the quantity of caloric which they contain; but this caloric, upon the presence of which depends their permanent state, is not perceptible to the thermometer; it exists as latent, or specific caloric.

This hypothesis has been embraced by the greatest number of chemists and mechanical philosophers.

CCXXXIII. The opinion that caloric is merely a quality of bodies or vibratory motion, is sanctioned by the names of Bacon, Hooke, Boyle, Newton, Macquer, Rumford and Davy. It is assumed, that in solids the phænomenon of heat results from a vibratory or undulatory motion of their particles, the temperature varying with the spaces between them, and the intensity of the vibrations; that in liquids and gravitating elastic fluids, the vibration is accompanied with a motion of the particles around their own axes, those of gaseous matter being performed with the greatest velocity; and that in ethereal fluids or radiant matter, the particles move around their own axes, and separate from each other penetrating in right lines into space. Temperature may be conceived to depend upon the velocity of the vibrations; increase of capacity upon the motions being performed in greater space; and the diminution of temperature during the conversion of solids into liquids or gases upon the idea of the loss of vibratory motion in consequence of the revolutions of the particles upon their own axes, at the moment when the body becomes liquid, or aëriform, or from the lessened rapidity of vibration from the motions being performed in a greater space.*

CCXXXIV. The principal arguments in favour of this hypothesis are derived from the facts, that friction and percussion produce high temperatures, and that much heat is manifested during chemical combinations and decompositions which are not followed by condensation.

Friction occasions heat, and yet there is no apparent permanent approximation of the particles of the bodies employed. The only mode by which it can be explained, upon the supposition that caloric is material, infers an identity between this agent and electricity, which neither observation nor experiment has verified.

The reason why a metal, which has once been heated by percussion, cannot have its temperature raised in the same way a second time, may be that the pressure applied has so

* Davy's Elements, Part 1. p. 95.

altered the relative arrangement of the particles as to destroy their power of vibratory motion, until by being heated and cooled, the particles have resumed their original situation.

In many chemical combinations and decompositions, high temperatures are produced, and yet the capacities for caloric remain the same or are increased. It must be inferred, therefore, either that caloric is not matter, or that if material and previously combined with the bodies, it is not given out in consequence merely of condensation; for these instances are opposed to what has been considered as a general law in chemistry, that caloric is absorbed during the rarefaction, and evolved by the reduction in volume of bodies. The heat thus produced by explosive compounds has been supposed, by those who favour the hypothesis of the materiality of caloric, to be still combined with the elements, notwithstanding they have been reduced from the gaseous or liquid to the solid form. Thus in the example of gun-powder, the elements, when they combined to form nitric acid, must have preserved the caloric which was essential to their gaseous state, and the same circumstance must have happened when the acid was combined with potash, and the whole converted into a crystalline solid or nitre. But this mode of obviating the difficulty is far from being satisfactory, and facts like the one just mentioned cannot be explained upon the principles of that hypothesis. Yet if heat be supposed dependent upon vibratory motion, and these motions be performed with a velocity proportionate to the intensity of chemical action, the high temperature produced by the ignition of explosive compounds may be accounted for without difficulty. In fact, wherever chemical affinity is suddenly and intensely exerted, whether it be or be not followed by condensation, heat and often light are perceptible. The caloric manifested in common cases of combustion, cannot be ascribed exclusively to changes in capacity, and it will probably be found necessary to give up either the hypothesis of the materiality of caloric, or the doctrines of Crawford and Irvine.

CCXXXV. The phænomena of Light, like those of Caloric, likewise admit of two different modes of explanation. They have been supposed by some to depend upon vibrations produced in an highly subtle fluid, which fills all space ; and by others upon the existence of indefinitely small particles thrown off in right lines from luminous surfaces.

CCXXXVI. The first hypothesis was formally proposed by Huygens, and supported by Euler. It assumes the existence of an exceedingly rarefied and elastic fluid, which fills all space, and which has been called ether. Light is produced by impressions made upon this ethereal fluid by bodies that appear to us luminous, this impulse causing undulation or a vibratory motion, which is transmitted through it with great velocity in spherical superficies proceeding from a centre. These vibrations striking upon the eye produce motions which are propagated by its different parts to the retina, and occasion the phænomena of vision. On this hypothesis may be explained the phænomena of the reflection and refraction of light ; the equality of the angles of incidence and reflection, and the constant ratio which is found to subsist between the sines of the angles of incidence and refraction. And by granting that these undulations are propagated through transparent, crystallized bodies, in spheroidal instead of spherical waves, all the phænomena of double refraction and polarization of light may be demonstrated.

Independently of what has been stated above, the arguments in favour of this hypothesis are of a negative kind, and are derived from the difficulty of giving a satisfactory explanation of some of the properties or phænomena of light upon the assumption that it is matter.

CCXXXVII. The foundation of the theory of the material nature of light was laid by Sir Isaac Newton. It supposes that the rays of light consist of minute particles, which are wonderfully elastic, and which of course repel each other while they are attracted with energy by other matter. These particles when thrown off by luminous surfaces move with

great velocity in right lines through space ; and when they impinge upon any obstacle, they are either absorbed, reflected, or transmitted, according to the nature of the opposing body, or the angle at which they strike. The matter of light possesses no apparent gravity. It is capable of combining with, and of being again separated from terrestrial bodies, and it produces the phænomena of vision by entering the eye, and causing a direct impression upon the retina. “Nothing more is requisite for producing all the variety of colours and degrees of refrangibility, than that the rays of light be bodies of different sizes, the least of which may make violet the weakest and darkest of colours, and the most easily diverted from a straight course by refracting surfaces.”*

CCXXXVIII. The arguments in favour of this theory, and against that of Huygens, are 1. That the phænomena of refraction, and even of reflection in particular circumstances, demonstrate that an attractive force subsists between common matter and the cause of light. 2. That colours are qualities of light, and therefore light is matter. 3. That if light resulted from the vibratory motion of an elastic fluid, there could be no darkness. 4. That if light consisted in pression or motion propagated either in an instant or in time, it would necessarily bend into the shadow ; or in other words, that as undulations are transmitted in all directions, they must pass by the sides and meet behind any obstacle opposing their progress, and thus prevent the formation of a shadow. Hence the sun and planets should be visible during eclipses. 5. That the formation of shadows proves that the cause of light moves in a rectilineal direction, and is therefore consistent only with the theory of emission.

CCXXXIX. To the Newtonian hypothesis, the principal objections are, 1. The incredible velocity of light. 2. The improbability that such immense quantities of matter should be continually discharged from the sun, without materially diminishing the volume of that luminary. 3. The momentum

* *Opera Newtoni*, t. iv. p. 300. Ed Horsely.

which the particles of light, even supposing them to be wonderfully minute, must acquire in their passage through so vast a space. 4. The probable interference of the particles radiated from every point of terrestrial as well as celestial bodies. 5. As transparent bodies transmit light, they must have pores or canals in all directions, which must have the effect to weaken cohesion and prevent solidity. 6. Newton himself, in order to account for the phænomena of vision, and for his fits of easy transmission and reflection, was obliged to assume the existence of an ether. To obviate the force of these arguments, calculations have been made, the results of which tend to show, that they are not inconsistent with the hypothesis of the emission of luminous particles, and granting the correctness of the data, they appear satisfactory. It must be remarked however, that many of the positions are hypothetical, and the results exposed to uncertainty.

CCXL. From the period when electrical phænomena first attracted the attention of philosophical men, until within a comparatively short time, no doubt was entertained that the cause which produced them was material. But in reasoning upon the facts then known, opinions opposed in a certain degree to each other, were adopted and defended. By some it was thought necessary, in order to form a system which should be considered as an expression of facts, to suppose the existence of two fluids; while by others the phænomena were considered to be explained in an equally satisfactory manner upon the assumption of one fluid. The hypothesis of Dufay and Symmer of vitreous and resinous electricity, has been supported by the most eminent of the French philosophers, and the mathematical analysis has been rigorously applied to demonstrate its correctness by M. M. Coulomb, Poisson and Biot. It has also received the sanction of some of the learned men in Great Britain. It is in substance as follows.

CCXLI. The electric fluid is diffused through all bodies, and the globe contains an inexhaustible quantity, whence it is called the common reservoir. In this state, it is a com-

pound of two fluids, such as are exhibited respectively by excited glass and resins, and hence named the vitreous and the resinous. When these fluids are separate, the particles of each exert among themselves a repellent power, but the particles of both are mutually and strongly attractive. There results therefore four different forces between the fluids of two bodies, namely, two attractions and two repulsions. When the two fluids are combined, the electricity is in its natural state, and no signs of excitation appear in the body in which it is present. But if it be decomposed, and it may be done by friction &c. then the body becomes electrified and exhibits phenomena, varying according to the mode by which the decomposition is produced. The fluid, whether vitreous or resinous, exists only at the surface of bodies, and surrounds them in the form of an atmosphere, which is retained by the pressure of the air. The resistance of this electric atmosphere is proportional to the square of the thickness; when it is less than that of the air it is retained, when greater at certain points of the surface it escapes and gives rise to electrical discharges.

Electricity and its component fluids exert no affinity for, and do not combine with the bodies in which they are present. Those bodies are considered merely as reservoirs. The repulsion which takes place between the particles of the same fluid, is in the ratio of the density, or of the number of molecules in a given space; and the attractive forces of the two fluids for each other is inferred to follow the law applied by Sir Isaac Newton to masses of matter, viz. inversely as the squares of the distances. The forces which produce motions in bodies electrically excited are the mutual attractions or repulsions between the fluid of one body, and the fluid of another body. After friction the two bodies employed in the experiment exhibit, the one vitreous, the other resinous electricity. When an excited body A is brought into the neighbourhood of an insulated conductor B in the natural state, the combined electricities of the latter will be separated; if A be

resinous, the resinous fluid of B will be repelled to the farthest extremity of the conductor, the vitreous electricity will be attracted to the point nearest the body A, and the middle point will be neutral. The two free electricities of B will then react upon that of A and even decompose a portion of its combined electricity, and this action and reaction taking place continually, the electrical phænomena must be proportionally exalted. When A is withdrawn, the two electricities in B again unite, and the electrical signs disappear. This explains the mode in which electrical phænomena are produced at a distance, or the process which has been called electrical influence or induction. It appears that the two fluids exist in bodies in the proportions necessary for neutralization.* In this hypothesis, the distribution of electricity is inferred to take place according to the laws of Hydrostatics.

The heat and light which are developed during an electrical discharge are considered as the results of a sudden and great compression of the air.†

CCXLII. The hypothesis of Dr. Franklin was more simple than that of Dufay. In contemplating electrical phænomena, he supposed that they might be explained upon the supposition of the existence of *one* instead of two fluids; and his opinions were adopted, and submitted to the mathematical analysis by Æpinus and Cavendish.

In this hypothesis, it is taken for granted that the phænomena of electricity are produced by an highly attenuated fluid, the particles of which repel each other, while they are attracted by those of other matter. This electric fluid is diffused throughout all bodies, but not in the same quantity; for in consequence of a difference in the attractive forces, some bodies not only contain a larger proportion, but retain it longer than others. When thus diffused in substances in quantities peculiar to each, it exists in a state of equilibrium, and the matter in which it resides exhibits no electrical excitation. It is supposed to have nearly as much as it can contain, for if

* Biot. *Traité de Physique*, t. ii. p. 284.

† Ibid, p. 459.

a little more of the electrical fluid be added, the additional portion does not enter the body, but is diffused upon the surface in the form of an atmosphere, which may be drawn off much more easily from angular than from spherical bodies.* By certain processes, e. g. friction, the equilibrium is destroyed, and after the operation, the two bodies will be found to be in two opposite electrical states, answering to the vitreous and resinous electricities of Dufay. It is here supposed to be the consequence of one body having received a portion of the fluid from the other; the former, therefore, will contain more, and the latter less than its natural quantity. Hence one is said to be electrified plus, and the other minus, or the former to be in the positive, and the latter in the negative state. When a communication is effected between them by a conductor, the redundant quantity of electricity in A passes into B, and the natural electrical equilibrium is restored; the same effect is produced by bringing them successively into contact with the earth, which Franklin expresses by the terms, common fund, for A will discharge, and B attract or receive electricity, until they are both brought into the neutral state.

In the hypotheses of *Æpinus* and *Cavendish*, the electric fluid present in a body is inferred to be proportional to the mass; and as an attraction is stated to obtain between this fluid and common matter, the analysis of the forces has led them also to the conclusion, that the particles of different bodies admit of a repulsion between them at sensible distances. Dr. Franklin was satisfied with a less rigorous demonstration of the principles of his theory, and they were most ingeniously applied by him to the solution of electrical phenomena.

It has however been objected to this hypothesis, the objections being grounded upon the doctrines of *Æpinus* and *Cavendish*, that one of its fundamental propositions is inadmissible, namely, that the particles of all bodies repel each other, which is inconsistent with the law of gravitation. It

* Franklin's Works, vol. i. p. 219. Eng. Ed.

has also been said that it is incapable of explaining why negative electricity, which is here considered merely as the absence of electricity, should be exhibited at every point upon the surface of a body conformably to the laws of hydrostatics, by which a fluid, the particles of which repel each other inversely as the squares of the distances, must be uniformly diffused; and why electricity should be divided between the surfaces of two bodies according to laws, which are altogether independent of their composition, and determined solely by their dimensions. Much less can it resolve the question why, when two spheres of conducting bodies are withdrawn from contact, signs of an electrical state different from that of the balls themselves are developed around the points of contact of the smallest sphere; while the necessity, the limits, and the constancy of this developement in the latter may be explained with the greatest facility, and calculated even to the most minute circumstance with surprising exactness, upon the theory of two fluids.*

CCXLIII. An hypothesis, differing essentially from those of Dufay and Dr. Franklin, has been stated by Sir Humphry Davy. Electricity is conceived by this distinguished chemist to result from the general powers or agencies of matter, and its phænomena to be displayed in the attractions and repulsions between different bodies or their particles. In these cases they assume a polar arrangement, and the opposite extremities are dissimilarly electrified, the positive pole of one being opposed to the negative pole of the other. The effect is proportional to the violence with which the electrically attractive and repellent powers are exerted, and may be connected with the motions of the particles of the substances affected. The difference in what has been called the conducting powers of bodies, seems to depend entirely upon the different manner in which they receive the electrical polarities, or in which their parts become capable of communicating attractive or repellent powers to other matter. When an

* Biot. *Traité de Physique*, t. ii. p. 315.

excited body is brought into the neighborhood of an insulated conductor, the air being interposed, the nearest point of the conductor becomes dissimilarly electrified, the remote extremity similarly electrified, and the middle is in a neutral state. The conductor here acquires polarity with ease, and exhibits but two poles, and this polarity is *induced* by the proximity of the electrified body. The polarities of the two bodies may continue to be exalted, until they are annihilated through the air, producing what is commonly called an electrical discharge. The phenomena of sparks, discharges, and accumulated electricity, depend upon this law. The particles of different bodies are also inferred to possess inherent electrical energies, and it is considered as not improbable, that the same arrangements of matter or the same attractive powers which place bodies in the relations of positive and negative, i. e. which render them attractive of each other electrically, and capable of communicating attractive powers to other matter, may likewise render their particles attractive and enable them to combine, when they have full freedom of motion. Hence electrical and chemical phenomena may depend upon the same power, in the former case acting upon masses, and in the latter upon the particles of matter.*

Let us now turn our attention to the relations which are known to subsist between Caloric, Light, and Electricity.

CCXLIV. The similarity in properties exhibited by caloric and light is remarkable. They are both radiated into space in a rectilineal direction; they are susceptible of reflection, of refraction, and of polarization; they are arrested in their progress by some surfaces, and transmitted through others; their velocity is wonderful, their momentum inappreciable, and their weights are unknown. Both may be absorbed by bodies, and the surfaces which reflect the least light, absorb the most caloric, while those which receive and radiate heat with the greatest facility, possess the faculty of extinguishing the most light.

* Davy's Elements, Part i. pp. 125—180.

CCXLV. Light and Caloric are frequently associated in the operations and changes to which the matter of our globe is exposed. Bodies require only to be raised to a certain temperature to become luminous. The more intense the temperature the more brilliant is the light, so that in general the power of light to impress the organ of vision is proportional to the degree of heat. The degree to which bodies are heated may often be ascertained by the kind of light which they exhibit. Red light accompanies low degrees of ignition, as the temperature rises, the colour becomes brighter, and continues, with the increase of heat, to grow more dilute until at length all colour disappears, the mass glows with a dazzling white light, and appears translucent. Ignition may be produced likewise by friction and percussion, and it is frequently an accompaniment of chemical action. It is shown in the common process of combustion, and in other combinations and decompositions which are sudden and violent.

It was the opinion of Hooke and Newton, that flame was vapour heated red-hot; and the fine experiments of Sir H. Davy favour the conclusions, that flame results from the ignition of solid matter in combustion, and that the light and heat which accompany this process may be considered as independent phenomena. He has also found that compounded gaseous or vaporious matter, although they do not always during combination or decomposition, become luminous, are yet capable of communicating this property to solid bodies, particularly to those which are considered as imperfect conductors of caloric. Even heated air alone will cause the emission of luminous rays from any body in the solid form when confined in its current, as was decisively proved by Mr. Wedgewood.

CCXLVI. Light it is well known is exhibited by certain substances which have acquired the name of phosphori. By one class, this effect can be produced only by previous exposure to the impression of the direct or the reflected solar rays, or at least to the influence of the radiant matter thrown

off in cases of combustion. When removed from these sources the light, which it is presumed must have been absorbed during the exposure, is gradually given out, and these bodies thus possess the property of phosphorescence. Now it is not probable that light alone enters into the substance of the phosphori while the caloric is reflected, for the surface which is adapted to the reception of one is equally disposed for the absorption of the other; and as the luminous matter is again evolved, it can hardly be supposed that the caloric is passive; and it is impossible at present to say, what influence may be exerted by the association of light and heat in these experiments upon the phosphorescent property of the bodies. In some cases, phosphorescence is spontaneous, but certain conditions are necessary for the production of light. Animal matter possesses this property, and as it is developed only after life has been extinct for many hours, it may probably be connected with an incipient decomposition, and this kind of decomposition is accompanied with rise of temperature. The increase of heat, however, has not been observed in these cases of phosphorescence, but the reason may have been that the masses were too small, or that the circumstances, under which the experiments were made, were not favourable.

CCXLVII. The experiments of Rochon, Herschel, Wollaston, Ritter, and others, have been considered as demonstrating in the solar beams the existence of at least three distinct species of radiant matter, namely, the colorific, the calorific, and the de-oxidizing, or chemical rays. If this conclusion be adopted, it must be inferred with M. M. Berthollet, Chaptal, and Biot, that when the rays of the sun are decomposed by the prism, there must be formed behind it three spectra, one above the other, viz. a coloured, an heating and a chemical spectrum. It must be admitted, likewise, that each of the three substances which compose these spectra, and even each particle of unequal refrangibility is endowed, like the molecule of visible light, with the property of being polarized by, and escaping from reflection in the same lines as the

luminous particles, &c.* Besides these, each of the coloured rays, ought upon this theory to be considered as composed of a distinct matter, so that the radiant substance of the sun ought to be regarded as a compound of seven species of fluids which form the prismatic colours, of one species which produces the phenomena of heat, and of one on which depend the chemical effects. The power of effecting chemical decomposition having been found to exist in greatest intensity at the violet end of the spectrum, where there is the least light and heat, it was concluded that the cause must be material and distinct both from the luminous and the heating rays. Count Rumford, however, instituted some experiments, and employed some ingenious reasoning to show that the same effects might be produced by heat alone; and it seems to have been demonstrated by M. M. Gay Lussac and Thenard, that the changes in colour and in composition by the action of light might be completed by a degree of heat not less than 212° . If this conclusion be correct, it must be inferred upon the hypothesis of the materiality of light and heat, either that the chemical ray is a modification of caloric; or that caloric is compounded of the heating and de-oxidizing rays.

According to the experiments of De la Roche, radiant caloric traverses solid transparent media with a facility proportional to their temperatures, and experiences the least difficulty as the bodies approach the point at which they become luminous; it would appear, therefore, from these results, say the French philosophers in the memoir alluded to above, that the modification, whatever it may be, which must be impressed upon the invisible rays, to render them more and more capable of passing through glass, makes them approach more and more to the state in which they must be when they penetrate the eye, and occasion the sensation of vision.

CCXLVIII. Light and heat differ obviously from each other in two properties. Caloric causes in us the sensation of heat, while upon light depend the phenomena of vision.

* Report on a memoir of M. Berard, *Annals of Philos.* vol. ii. p. 166.

The one may apparently produce its specific effects independently of the other, and though often associated, light it has been affirmed is not necessarily accompanied by heat, nor is caloric so far as we know ever the medium of vision.

The independent existence of light has been supposed to be proved in the rays of the moon. When these rays are brought to a focus by a powerful lens, and thrown upon the bulb of a thermometer, no rise of temperature is perceptible; nor when directed upon the eye is there a sensation of heat experienced in that susceptible organ. Mr. Leslie, who has given us the ratio of the intensities of solar and lunar light, arrived at his conclusion by indirect experiment, for the rays of the moon exerted no positive influence even upon his delicate photometer. The light of this satellite has been estimated, by this ingenious philosopher, to be 150,000 times weaker than that of the sun. But if the light be derived by reflection from the sun, it must be accompanied by caloric, for the same disposition which enables the lunar surface to throw off the luminous rays will cause it to reflect the rays of caloric, and the only conclusion which can be drawn from Mr. Leslie's calculations is, that the radiant caloric of the moon, like the impression of its light, is 150,000 times less than that of the sun.

CCXLIX. From this concise view of the relations of Caloric and Light, and the limits of this work forbid us entering more into detail, it will appear that an intimate resemblance exists in their properties. It may then be asked, does it not render the opinion probable, that the effects of both depend upon the same cause? Upon the supposition that this cause is material, may not its modes of action result from a difference in the size and refrangibility of its particles? May not the query of Newton, whether the different coloured rays be not caused by the different sizes and refrangibilities of the particles of light, be extended further, and allow us to believe that the particles beyond the red ray are larger, and those on the violet side smaller than the particles which constitute the prismatic spectrum? And may not the former produce the

phænomena of radiant heat, and the latter those of chemical decomposition? Why, ask the French chemists, ought these rays to produce upon thermometers, or upon our organs the same sensations of heat or light? Why should they have the same energy to form or separate combinations? Would it not be quite natural, that light should not operate upon our eyes except within certain limits of refrangibility; and that too little or too much refrangibility should render it equally incapable of producing vision? Perhaps these rays may be visible to other eyes than ours; perhaps they are so to certain animals, which would account for certain actions that appear to us marvellous. In a word, we may conceive the calorific and chemical faculties to vary through the whole length of the spectrum, at the same time with the refrangibility, but according to different functions; so that the calorific faculty is at its minimum at the violet end, and at its maximum at the red end of the spectrum; while, on the other hand, the chemical faculty, expressed by a different function, is at its minimum at the red end, and at its maximum at the violet end, or a little beyond it.*

In this hypothesis, the radiant matter of the sun is conceived to be composed of one and the same substance, but differing in the size and refrangibility of its particles. It obviously differs from the one which was maintained some time ago, and in which caloric and light were considered to be identical, but differing in their states with regard to motion, the former being quiescent, and the latter in rapid progression. It also weakens the force of some of the arguments which have been brought against the opinion of the identity of the two principles. For it has been objected, that caloric is diffused over matter slowly and equally, and penetrates every body. It is the cause of expansion, fluidity, and vaporisation. It produces the sensation of heat, but is incapable of exciting illumination. Light possesses very different properties; instead of merely raising the temperature of bodies, it produces in

* *Annals of Philosophy*, vol. ii. p. 166.

them chemical changes, which do not arise from the operation of caloric. Such essential differences in properties, and especially in chemical powers, seem sufficient to authorise the conclusion, that they are totally different kinds of matter.*

CCL. But the phænomena of Light and Caloric, it has been thought, may be explained independently of the assumptions of specific luminous and calorific fluids. Newton supposed that heat was the result of vibrations in ponderable matter, and that when the vibration was rapid or intense, particles might be sent off into space in right lines, and might lose their own motion in communicating vibratory motion to other bodies. This philosopher also entertained the idea of the possibility of the mutual convertibility of light and other matter. In explaining the phænomena of light and radiant caloric the existence of matter as the cause or medium must be assumed. The formation of shadows, and the aberration of light from the fixed stars, prove not only that substance must exist between us and the celestial systems, but that its particles must also assume a rectilineal direction. As particles of any gaseous medium when put into a state of undulatory motion are capable of producing the sensation of sound by acting upon the auditory organs, so it may be conceived, that certain particles or aggregates of particles, moving with great and uniform velocity, may occasion the sensations of vision, and the other effects of the solar beams,—and, according to the Newtonian hypothesis, any matter moving with considerable quickness in right lines may be conceived capable of communicating an expansive motion to the particles of bodies.† The matter, then, upon which depend the phænomena of solar light and radiant heat may receive its impulse from the sun, and in consequence of the intensity of the vibration, its particles may be sent into space, and when they impinge upon terrestrial bodies may occasion in them vibrations which raise their temperature, or cause them to throw off particles or aggregates of particles, producing the phænomena of vision.

* Murray's System of Chemistry, vol. i. Note C.

† Davy's Elements, Part i. p. 218.

If specific, highly rare, imponderable fluids be assumed to account for the phænomena, as many must be adopted as there are different series of effects produced by different rays. There must be a matter of violet light, a matter of blue light, and so on; and likewise a de-oxidating ethereal matter, a calorific solar matter, and a calorific terrestrial matter, which is very contradictory to the usual simplicity observable in the economy of things. The appearances presented by the solar phosphori are also adverse to this idea, for to whatever ray of light Canton's phosphorus is exposed, the colour of the light which it emits is constantly the same, viz. a pale yellow. But if light be supposed specific in its kind, and absorbed and emitted, the substance ought to shine with the colour of the light to which it had been previously exposed, which is not the case; but it is easy to explain the phænomenon on the idea, that vibratory motion is communicated to particles of the substance by the rays, in consequence of which, some of its own are slowly sent off, or that the particles of light have been formed into new aggregates, in consequence of the attraction of the substance.

The fire produced in a number of chemical processes, particularly in combustion, on the Newtonian view, may be ascribed to particles sent into free space, in consequence of the repulsion exerted by other particles at the moment of their entering into chemical union.

The light produced during the putrefactive process in organic bodies, by certain living animals, by friction, percussion, &c. may be explained upon the same principles. In many instances, the phænomena which have been attributed to *combined* light, appear to be electrical, or to be the effects merely of the ignition of the bodies.*

CCLI. An intimate connexion appears to subsist between electricity, light, and caloric. As bodies require to be raised only to a certain temperature to become luminous, so it is only necessary that the electrical excitation should be increas-

* Davy's Elements, p. 123. Amer. ed.

ed to a certain point to render them radiant. The effect of lightning in setting fire to combustibles is well known. The electricity excited by friction will inflame combustible liquids, gun-powder, and the metallic, exploding compounds. Transmitted in large quantity through the perfect conductors, it melts and dissipates them in globules. The temperature produced in the circuit of the batteries of Mr. Children and of the Royal Institution of London, was probably equal or nearly so to that of the flame of the oxy-hydrogen blow-pipe, which is the highest that can be effected by art. Electricity even of low intensity is accompanied with light. The spark is familiar, and the star which is sometimes observed stationary upon the point of a conductor is brilliant and well defined. A variety of bodies when electrically excited become phosphorescent, and non-conductors subjected to friction are rendered luminous. The colour of the light is not always the same; it varies according to the intensity of the excitation, the distance to which it is to be transmitted, and the nature of the medium which opposes the action. In low degrees of excitation, the colour is red, in proportion as they are exalted, it becomes purplish, and when intense, white with a shade of violet. The characters of electrical light are the same as those of solar light.

We see in this instance an analogy between caloric and electricity; the kind of light evolved by bodies exposed to their influence, depending upon the intensity of their action. The analogy has also been extended to the phenomena of the solar spectrum. The rays at the red end in their chemical powers tend to burn bodies or to combine them with oxygen, those at the opposite end tend to restore inflammability to bodies, and negative electricity, which exercises the same function, produces hydrogen gas from water, and the inflammable bases from their combinations.*

CCLII. If the agents, the nature of which has been considered in this chapter, be material, it seems to follow either that

* Davy's Elements, p. 224.

electricity in its passive state is compounded of three or four different fluids, or, that when in motion, it combines with caloric and light, and then causes their evolution; for these phænomena are exhibited in circumstances, in which their production cannot be attributed to sudden and great compression of the air.

Electrical light is susceptible of refraction, and by the prism may be separated into the seven primary rays; but as caloric accompanies this light, we may conclude that the same phænomena are exhibited here as in the solar spectrum. Both the heating and the chemical rays may therefore be present; and as there appears to be no just reason, upon the commonly received theory, why each of the colorific rays should not be regarded as a distinct species of matter, the conclusion may be drawn, that electricity is a compound of many kinds of ethereal fluids. We ought not perhaps to say that this is contrary to the usual simplicity of nature, because we can judge but very imperfectly in what this simplicity consists, but it requires a great deal of faith to believe that this is a just expression of facts.

CCLIII. The connexion which subsists between light and electricity will appear still more evident, when they are viewed in relation to magnetism. The operations both of this last power and of electricity are shown in attractions and repulsions, and their most obvious actions are upon masses of matter; but there can be but little doubt that the same powers influence the particles of bodies, and that both produce polarities. The present theory of magnetism is founded upon the doctrine of two fluids, the austral and the boreal, the one answering to the vitreous, the other to the resinous electricity of Dufay: and the laws which govern the motions and combinations of the latter have been demonstrated to be equally applicable to those of the former. Polarity or the phænomenon of magnetism may be communicated to iron by electricity; and it has been satisfactorily proved that the assertion of Morrichini was correct, that the same effect may be produced

upon the metal by the violet ray of the solar spectrum. Riddolfi has not only succeeded in magnetising a needle in this way, but he has also pointed out the causes which rendered the attempts of others unsuccessful, and the fact itself is now considered as established.

Radiant matter has been demonstrated by Malus and Bérard to be susceptible of polarization. Newton supposed that their particles, at least those of light, might be presented by different surfaces to those of the particles which compose crystallized bodies, in consequence of which, while some were refracted in the usual way, others would be refracted in the extraordinary way, so that the forces which produced these effects might be compared with those of a magnet. It was inferred by Malus, that the particles of light possess three rectangular axes, two of which are in relation to the action of certain forces, and that polarization might be accounted for upon the principle of the different directions in which the repulsive forces operate in the crystalline medium through which they pass. This phenomenon must depend upon the arrangement of the particles of the transparent bodies through which those of light are transmitted, but the latter produce no permanent effect upon the former. How polarity is communicated by the violet ray to iron is a mystery which must be left to future researches and experiments to determine; but in assuming that electricity is an exhibition of the inherent attractive and repellent powers of matter, and that the caloric and light which often accompany these phenomena are the results of vibratory motion communicated to bodies, the particles of which, when the motions are intense, are radiated into space, the connexion between caloric, light, and electricity, may perhaps be explained upon an hypothesis more simple than that which refers their actions to the presence of three specific and independent fluids.

CCLIV. We have thus endeavoured to present a correct, but concise view of the opinions which have been entertained respecting the nature of Caloric, Light, and Electricity.

Each of them is more or less open to objections, and we must be satisfied with the adoption of the one which is applicable to the greatest number of facts. It is not necessary in order to acquire a knowledge of these facts, that either should be exclusively maintained. Newton demonstrated all the phenomena of light, before he ventured to deviate into hypothesis, and even then he expressed his opinion in the modest form of questions. In speaking, however, upon these subjects, the language of hypothesis must be occasionally, if not generally employed, but if it be remembered that this language is intended only as a mode of conveying a knowledge of facts, it will be neither misunderstood, nor misapplied. The hope was entertained by Newton, that at some future period, the essence of some of the elementary bodies might be discovered; but the probability of this discovery does not keep pace with the progress of science. The chemist has not probably even approached to the knowledge of the real essence of a single ponderable element. The nature and constitution of the simple bodies of which our globe is formed, and of the etherial matter which connects us with other systems, are hidden from our view, and whether they must always be regarded as ultimate facts, or whether the philosopher, in these instances, will ever triumph over Nature, cannot now be foreseen; but this is certain, that the more he investigates her operations, the nearer will he approach to truth, and the more he becomes enlightened, the less will he be ensnared by false theory, or checked in his progress by premature induction.



ELEMENTS
OF
CHEMISTRY.

=

PART II.

Of the Properties and Relations of Ponderable bodies ; and of the Compounds formed by their union with each other.

IN the preceding pages, having taken a very general view of the forces, from the operations of which are derived the laws of chemical science, we shall now turn our attention to the nature of individual bodies, and to the results of their mutual action.

CCLV. In operating upon different substances, it has been found by the chemist, that analysis can proceed only to a certain point, at which decomposition ceases, and bodies are obtained that admit of no further division, or of being resolved into no simpler forms of matter. To such substances has been given the name of Elements ; and it is now appropriated by the chemist to all undecomposed bodies, notwithstanding that analogy may favour the opinion of their compound natures.

It is at least doubtful whether the philosopher has yet arrived at the knowledge of a single simple body ; and in judging from the past, it is more probable, that in proportion as the art of analysis is refined, the substances which are now ranked among the elements will be decomposed, that new views of the species and constitution of matter will be opened to the chemist, and that even the primary arrangements of the science will undergo repeated modifications, and be exposed to successive revolutions. No limits can be assigned to

the progress of chemistry, for Nature, though she may operate with few materials, varies her productions to an indefinite extent, and the era at which the principles of the science may appear to be most permanently established, may be the age also most fertile in the discovery of facts, opposed to its doctrines, and incompatible with its laws.

At present, the number of elementary bodies amounts to 52, and they are thus named.

1 Oxygen	—	36 Cerium
2 Chlorine	19 Zirconium	37 Cobalt
3 Iodine	20 Glucinium	38 Titanium
4 Fluorine	21 Yttrium	39 Bismuth
—	22 Aluminium	40 Copper
5 Hydrogen	23 Thorium	41 Tellurium
6 Nitrogen	—	42 Cadmium
7 Silicon	24 Iron	—
8 Boron	25 Tin	43 Osmium
9 Carbon	26 Zinc	44 Mercury
10 Phosphorus	27 Manganese	45 Lead
11 Sulphur	—	46 Nickel
—	28 Arsenic	—
12 Potassium	29 Molybdena	47 Gold
13 Sodium	30 Chrome	48 Silver
14 Lithium	31 Tungsten	49 Platina
15 Calcium	32 Columbium	50 Palladium
16 Magnesium	33 Selenium	51 Rhodium
17 Barium	34 Antimony	52 Iridium.
18 Strontium	35 Uranium	

CCLVI. Such are the names of the apparently simple substances which compose the mass of our globe. On investigating their properties and those of the compounds which are produced by their union, we immediately perceive that they admit of a natural and convenient classification into two divisions. In one class, the subjects are combined or separated by the sole agency of the powers, the modes of action of which

have been already described, their motions are mechanical, and the relative forces with which they are united, or by which they are decomposed, are in many instances susceptible of mensuration ; although capable of assuming a symmetrical arrangement, they are destitute of organization, and unless acted upon by external and foreign causes, preserve for an indefinite time their forms, properties, and relations. In the other class, the ultimate elements of the compounds have been combined in a different manner, and exhibit very different properties ; they have constituted parts of living systems, and the vital powers with which they were endowed, have brought into action new and powerful forces which appear to have exalted or diminished, modified or controuled, the operation of the common laws of affinity, according to the structure of the organ, and the function which it was destined to perform. The chemist, after he has decomposed a compound of the first class into its elements, may combine them anew, and form a body with the same properties and relations ; but when he has once separated the constituents of a compound of the second class, his power is at an end, and he acknowledges the impotence of his art. From these circumstances, the subjects of the following pages may be divided into *Organized* and *Unorganized Bodies*.

DIVISION I.

Of the chemical properties of Elementary bodies ; and of Compounded Unorganized Matter.



In this division, the elementary bodies and their combinations may be arranged under three heads.

1. Supporters of Combustion.
2. Inflammable or acidifiable unmetallic bases.
3. Metals.

CHAPTER I.

OF THE SIMPLE SUBSTANCES, SUPPORTERS OF COMBUSTION;
AND OF THEIR COMBINATIONS WITH EACH OTHER.

CCLVII. The term *Supporter of combustion* has been applied by Dr. Thomson to those substances which must be present before combustible bodies will burn. But it is somewhat indefinite in its meaning. If this process be restricted with Lavoisier to the combinations of oxygen with inflammable substances, the term is applicable only to one body; but if combustion be defined a change in properties, accompanied with the copious emission of light and caloric, a great variety of bodies, both simple and compounded, must be considered as supporters of this action, and the phænomena which are supposed to characterize this process will be found to depend less upon the presence of a particular species of matter, than upon the forces of affinity exercised at the moment of union. This subject will be considered more at large in a future chapter, and at present it may be sufficient to remark, that the simple bodies which are to be immediately described, form a class, the properties of which are characteristic, and by which they may be distinguished from all other classes of matter. One of these properties is the power of supporting combustion in a greater degree than has been observed in other cases, and they will be noticed in the order of their powers in this respect. There are four individuals belonging to this class, viz.

- | | |
|------------|-------------|
| 1 Oxygen | 3 Iodine |
| 2 Chlorine | 4 Fluorine. |

SECTION I.

Of Oxygen.

CCLVIII. This highly important and interesting element was discovered in August 1774 by Dr. Priestley, and by Mr. Scheele, who was ignorant of Dr. Priestley's experiments, in

1777. By the former it was called dephlogisticated air, and by the latter, empyreal air. Condorcet gave it the name of vital air, and Lavoisier that of oxygen, from the two Greek words *ὄξυς* *acidum*, and *γεννομαι* *gignor*, because one of the most general properties of this substance is to form acids.*

It may be obtained with facility from many individuals of the classes of salts and oxides. An ounce of nitre yields by distillation at a low read heat, about 300 cubic inches of this gas, and the chlorate or oxy-muriate of potash by the same process affords one third of its weight of oxygen in a state of great purity. It may also be procured in the same way from the red oxides of mercury and of lead, and in fact from other compounds of oxygen and the metals, in which the affinity with which they are united is feeble. The cheapest and most convenient material for the purpose is the mineral called black oxide of manganese.† A quantity of this substance, free from spar, or carbonate of lime, with which it is occasionally mixed, is to be coarsely powdered, and put into an iron bottle, or an earthen-ware retort previously coated with sand and clay, or a mixture of lime and solution of borax, and deposited in a furnace. To the mouth of the retort is connected a tube which opens into a gazometer,‡ or a common water-trough, having a receiver filled with water, and mounted upon its shelf § The joinings are made air-tight. Heat is then applied to the body of the vessel, and when it becomes obscurely red, oxygen gas is disengaged in abundance, and passes over into the receiver. A pound of the oxide of good quality will yield about 1260 cubic inches of this gas.

Oxygen may also be procured by putting a quantity of the same material in fine powder into a glass retort, moistening it with strong sulphuric acid, and exposing the mixture to the heat of a lamp. It passes over into the receiver mixed with another gas which renders it turbid and opaque, but from which

* Elements of Chemistry, vol. i. p. 80. Am. ed.

† Found in abundance and of a good quality at Bennington, Vermont.

‡ Plate vi. fig. 1.

§ Ibid, fig. 2.

it may be freed by standing for some time in contact with water. This mode of obtaining it, however, is troublesome in execution, comparatively small quantities of the gas are evolved, and the vessel is apt to be broken.

The gas from nitre, though sufficiently pure for ordinary experiments, is mixed with variable proportions of other elastic fluids. It is less adulterated when obtained from oxide of manganese; but for delicate analytical or synthetical researches, it should be procured from *chlorate of potash*, in which case it is mixed only with aqueous vapour. When it is required in a dry state, the vapour may be abstracted by exposing it to the action of sulphuric acid, quicklime, common caustic potash, or the deliquescent salts.

CCLIX. When procured by either of the processes above mentioned, oxygen exists in the form of a permanently elastic invisible, inodorous, and insipid fluid, indefinitely expandible by heat. Its specific gravity, compared with that of hydrogen, is as 15 to 1; and with an equal volume of atmospheric air as 1.1088 to 1.0000. At the temperature of 60° , and under mean barometrical pressure 100 cubic inches weigh 33.82 grains. Its specific caloric, or its capacity for heat, according to the experiments of Berard and De la Roche, is 0.8848, compared with an equal weight, and 0.9765 referred to that of an equal bulk of atmospheric air, as 1.0000. The specific heat of water being unity, that of oxygen will be 0.2361.

The number, by which a proportion of this element will be designated, is 7.5.

CCLX. One of the most remarkable properties of this gas is its prodigious power of supporting combustion. When a lighted candle is introduced into it, the flame increases in size, it emits a white and dazzling light, and the combustion is accompanied with a peculiar crackling noise. Charcoal, when previously ignited, burns in it with great vividness, and throws out occasionally sparks of intense brilliancy. Sulphur, instead of burning as in the open air with a pale blue attenuated flame, consumes in oxygen gas with rapidity, producing

at first a flame of a beautiful purple, which afterwards changes to a fine rose colour. The combustion of phosphorus is vehement, the vessel becomes filled with white fumes, and the light is so intensely bright as to produce a painful sensation in the eye. Even substances which can be inflamed only with great difficulty in the atmosphere, and in which the inflammation is still imperfect, may be made to consume with ease in this gas. If a coil of fine iron wire, having attached to it a filament of cotton previously dipped in melted sulphur and inflamed, be plunged into oxygen, the metal will soon take fire, and throw off ignited sparks of great brilliancy.

The temperature during the combustion of bodies in oxygen gas is proportionally exalted, and chemists have taken advantage of this fact to produce a circumscribed, but intense heat. A stream of this gas, directed through a small orifice upon burning charcoal, excites so high a temperature, that few bodies, even among those of the most refractory nature, can withstand its action. The oxygen may be made to pass from a gazometer through a fine tube tipped with platinum; or from a gas-holder, in which the air is compressed and forced out by a column of water contained in a conical funnel furnished with a stop-cock.* Dr. Marcett has ascertained that an efficient and convenient blow-pipe may be formed by propelling the stream of oxygen through the flame of a spirit-lamp.

CCLXI. Another distinguishing and important property of oxygen is its power of supporting respiration. In fact, it is the only gas which can be breathed by man for any length of time with impunity; and the power of atmospheric air, in this respect, is owing to the presence of oxygen. In respiration, a quantity of oxygen is taken into the lungs, it disappears, and its place is occupied by an equal bulk of carbonic acid. A reciprocal influence then is exerted between this aërial fluid and the circulating blood, and the continuance of life is dependent upon the due exercise of this influence, which appears

* Plate vi. fig. 3.

in the conversion of oxygen into carbonic acid. It has been thought, however, that when this gas is breathed in a pure state, it proves stimulating to the living fibre, and small animals confined in a definite portion of it, are said to show signs of apparent intoxication, and to die before the gas is exhausted. Such animals, however, will live four or five times longer in oxygen than in an equal bulk of atmospheric air. It may be breathed by men for some time without producing any other effects than a sensation of warmth, and slight stricture about the chest.

CCLXII. Oxygen gas is very slightly absorbed by water. When the liquid was previously boiled, Dr. Henry found that 100 cubic inches condensed about $\frac{1}{27}$ of its bulk, or 3.55 inches. Saussure Jun. makes it amount to 6.5 cubic inches. By strong pressure it has been asserted that water may be made to absorb one half its bulk of oxygen, but the sensible qualities of the liquid are not thereby altered.

CCLXIII. In all experiments in which inflammable bodies are consumed in oxygen gas, the product is found to be a compound of the basis of the gas and the combustible substance. The form of the product depends upon the nature of the element which is combined ; thus when charcoal is burnt, the resulting compound is elastic ; when hydrogen is consumed, it forms water, and phosphorus produces in dry oxygen a solid. The combustion then is to be considered as the act of union of oxygen and the inflammable bases, and it is often followed by a total change in the properties and relations of the combining bodies. M. Lavoisier, from observing that the products of this combination frequently discovered the properties of acids, too hastily concluded that oxygen was essential to the constitution of this class of bodies, and hence he was induced to apply to this element the name of oxygen. But that this generalization, that oxygen is the principle of acidity, was premature, will be perceived from this, that there are several acids, which have been proved not to contain oxygen ; and that the products of combustion in this gas are oxides, acids,

or alkalies, according to the nature of the combustible bases, and the proportions in which they unite.

CCLXIV. Oxygen, in the form of solid, liquid, or gas, is perhaps more widely diffused than any other elementary body, and it appears to perform a very decided and important part in the œconomy of our globe. It combines with all inflammable bas s ; it is a constituent part of the atmosphere, and of water ; and it enters into the composition of many mineral, vegetable, and animal bodies.

Its ponderable base has never been obtained in a separate state.

SECTION II.

Of Chlorine.

CCLXV. In the Dissertation of Mr. Scheele upon Manganese, which was published in the year 1774, it is stated, that when muriatic acid and the black oxide were distilled together, a yellow coloured gas, possessing some singular properties, was disengaged. It was considered by him as muriatic acid deprived of its phlogiston, and hence he gave to it the name of Dephlogisticated marine acid. Mr. Scheele regarded it as a simple body, and as constituting the base of muriatic acid. Some years after, M. Berthollet investigated the properties and modes of combination of this substance, and he drew as a conclusion, that it was a compound of muriatic acid and oxygen, and applied to it the name of oxygenized muriatic acid, which was afterwards abbreviated by Mr. Kirwan to oxy-muriatic acid. This view of its nature was supported by many satisfactory experiments, and much apparently correct reasoning, and no doubt was entertained of its truth, until 1809, when M. M. Gay-Lussac and Thenard showed, that the hypothesis of its simple nature might be supported.* Sir H. Davy soon after revived the opinion of Mr. Scheele in a more satisfactory and extended form, and from the results of his

* *Rechêrches Physico-Chimiques*, t. ii. p. 94.

experiments he supported the theory, that oxy-muriatic gas was a simple body, and analogous in properties to oxygen. He gave to it the name of Chlorine, from the Greek word *χλωρος*, signifying *green*. M. M. Gay-Lussac and Thenard, in 1809, read to the Society of Arceuil a memoir to the same effect, and they have claimed the discovery as their property. But the subject was not pursued by them, and the chief merit of having established the present theory of chlorine undoubtedly belongs to Sir H. Davy.

The theory of the simple nature of chlorine met with considerable opposition from Dr. Murray, and professor Berzelius. The first of these distinguished chemists published a series of valuable papers in Nicholson's Journal, in support of the hypothesis of M. Berthollet, which drew forth replies from Dr. John Davy; and the second has given in the *Annals of Philosophy* a comparative view of the two theories, and rejected the recent doctrine of the constitution of chlorine and muriatic acid. The late experiments of Dr. Ure, which have been repeated by Dr. Murray, appeared to strengthen the arguments against the hypothesis of Scheele, but the still later experiments of Sir H. Davy have shown that the results just mentioned were exposed to objections derived from sources of error in the experiments themselves. We shall advert to this question more particularly, after having described the properties of muriatic acid, and shall merely observe here, that according to all sound logical reasoning, chlorine must be regarded as a simple body.

CCLXVI. Chlorine may be obtained by mixing together three parts of common salt, and one part of black oxide of manganese in fine powder; this mixture is put into a tubulated retort connected with the hydro-pneumatic apparatus, and upon it are poured two parts of sulphuric acid previously diluted with an equal weight of water. An effervescence takes place, which may be increased by the application of a gentle heat, and after the atmospheric air is pressed out of the vessel, the gas may be caught in receivers. A considerable pro-

portion of this elastic fluid may be saved by employing water heated to the temperature of about 90° . In obtaining the gas, precautions must be taken against breathing it. The most convenient and expeditious mode of forming chlorine is to add to finely powdered manganese, contained in a tubulated retort, a quantity of liquid muriatic acid, sufficient to form a thin paste, and to apply the heat of a spirit-lamp.

CCLXVII. Chlorine is a permanently elastic fluid of a greenish yellow colour, and is therefore the only gas which is visible. Its odour is insupportably suffocating, and even when mixed in large proportion with atmospheric air, it produces cough and difficulty of respiration. In larger proportion it causes inflammation of the mucous membrane of the lungs. Its odour resembles in some degree that of sea air, and its taste is astringent. In its pure state it is fatal to animal existence. It is heavier than atmospheric air in the ratio, according to M. M. Gay-Lussac and Thenard, of 2.4700 to 1 0000. The specific gravity of hydrogen is 0.07321, and $0.07321 : 2.4700 :: 1 : 33.5$ nearly; hence the fourth proportional gives us the representative number for chlorine. An hundred cubic inches when the thermometer is at 60° , and the barometer at 30, weigh 75.33 grains. The weight of its atom, that of oxygen being 10, is stated in Wollaston's table at 44.10.

CCLXVIII. Chlorine supports combustion. A lighted candle when introduced into it continues to burn, but with a diminished red flame, and produces abundance of dark coloured smoke. Many of the metals when brought into contact with this gas take fire spontaneously, give out a brilliant light, and thick white vapours are formed. The metals which exhibit this property in the greatest degree are copper, tin, arsenic, zinc, antimony, and potassium; and they should be employed in thin leaves, filings, or in powder. An iron wire previously heated to ignition, and plunged into chlorine, continues to give out light, and the vessel becomes filled with dense yellowish red fumes. In making these experiments care must be taken not to inhale the vapours produced during the combustion of the metals.

When dry phosphorus is exposed to the action of chlorine, it inflames spontaneously, burning with a pale white light, and producing, if the gas be free from aqueous vapour, a white, volatile solid.

Sulphur melted or sublimed in chlorine does not take fire, but a combination ensues between them, and the result is a reddish yellow coloured liquid, which was discovered by Dr. Thomson, and named by him sulphuretted muriatic acid.

For the success of the experiments above mentioned, it is necessary that the gas be pure, and its temperature above 60° , or at least, the effect is more positive as the heat of the chlorine is increased.

Water at the temperature of 60° absorbs about double its volume of chlorine. The solution is of a light yellowish green colour, its taste is not sour, but styptic and disagreeable, and it exhales the intolerable odour of the gas. If the temperature of the water be reduced to 40° or below, it will be found, that when nearly saturated with the gas, small soft scales or crystals of a green colour are deposited, which continue to increase in proportion as the chlorine is applied, until the whole becomes nearly gelatinous. In favourable circumstances, this substance may be discovered in the form of regular quadrangular prisms. This soft solid is a compound of chlorine and water, and is therefore an *hydrate*. When heat is applied to the vessel in which this hydrate is contained, it is decomposed, and the chlorine in the elastic state rises in bubbles through the water. Phænomena owing to the same cause are observed to take place in a vessel filled with chlorine, which has been caught over water, whenever the temperature is less than 40° ; the hydrate is formed in a crystallized state upon the internal surface, and the odour is proportionally diminished. From this circumstance, it was once thought that the pure gas was capable of becoming solid at a moderate temperature, and some were disposed to rank it rather among the vapours than the permanently elastic fluids. But Sir H. Davy has shown that this property is owing to the presence of water,

and that when freed from aqueous vapour it is incapable of changing its form by exposure to cold.

CCLXIX. Chlorine possesses the remarkable and useful property of destroying vegetable colours. A piece of calico, or solution of a vegetable colour in water exposed to its action soon becomes colourless, or at least is changed to a very light shade of yellow, and the change is permanent, for the original colour of the substance can be restored neither by an acid, nor an alkali. An aqueous solution of chlorine produces the same effect. For this purpose, it appears to be necessary according to the experiments of Sir H. Davy, that water should be present; for when the gas had been previously dried by exposure to muriate of lime, it was found incapable of acting upon perfectly dry substances tinged with vegetable colours. It was in consequence of this property, that chlorine, under the name of oxygenized muriatic acid, was introduced by M. Berthollet into the art of bleaching.

When the compounds of chlorine are exposed to the action of voltaic electricity, the chlorine is attracted to the positive pole, and the base to the negative pole. It is therefore electro-negative with regard to all other substances except oxygen, for when combined with that element, it is probably separated at the negative surface; hence in relation to oxygen it is positive. In many cases the affinities of chlorine are stronger than those of oxygen, for it separates the latter from many of the oxides of the metals, and forms with them compounds which are called chlorides.

This gas when pure suffers no change, even when heated to whiteness.

Chlorine is capable of combining with oxygen in different proportions and of constituting four different compounds. A degree of uncertainty, however, still exists with regard to some of them, and experiments are still wanting completely to develop their properties and the relative amount of their elements. We shall adopt, in their description, the nomenclature of Dr. Thomson, and consider them separately

under the names of, 1. Protoxide of Chlorine. 2. Deutoxide of Chlorine. 3. Chloric acid. 4. Perchloric acid.

1. Protoxide of Chlorine.

CCLXX. Protoxide of chlorine may be formed by putting a quantity of chlorate or oxy-muriate of potash into a small glass retort, and pouring upon it twice as much muriatic acid as is necessary to cover it diluted with an equal volume of water. The beak of the retort is then connected with a mercurial apparatus, and the materials are exposed to a degree of heat short of 212° . A bright yellow coloured gas mixed with a portion of chlorine slowly passes into the receiver, and by allowing the mixed gases to remain some hours in contact with the mercury, the protoxide may be obtained in a state of purity, the chlorine combining with the metallic fluid. Much caution is necessary in collecting and examining this gas, for its elements are united by a feeble affinity, and a very gentle heat, even that of the hand, is sufficient to decompose the compound with explosion.

This gas was discovered in 1811 by Sir H. Davy, who gave to it the name of *euchlorine* from its lively green colour.*

The colour of this protoxide is brighter and more inclined to yellow than that of chlorine. It is a permanently elastic fluid, which is less irritating to the lungs than chlorine, and the odour of which has been compared with that of caromel or burnt sugar. It is however difficult to free it entirely from chlorine, and there is always more or less of the peculiar smell of the latter. Protoxide of chlorine is fatal to animal existence. It is soluble in water in much larger proportion than chlorine, the liquid condensing 8 or 10 times its own volume, and the solution has a lemon yellow colour.

It is decomposed with great facility by combustible bodies which have been previously ignited. When a lighted candle or burning sulphur is introduced into it, an explosion takes place, from the separation of its elements, and the bodies con-

* Elements of Chemistry, Part i. p. 238.

same in it with the same phænomena as are exhibited in a mixture of 1 part of oxygen and 2 parts of chlorine. Phosphorus, when it comes into contact with the gas, instantly decomposes it and then burns in the mixed gases. The metals which inflame in chlorine do not take fire spontaneously at common temperatures in the protoxide; but if the gas be decomposed by heat, while the metal is present, it will become ignited and burn with brilliancy.

When this protoxide is detonated in a glass tube standing over mercury, the gas loses its brilliant colour, and 5 volumes are expanded so as to occupy 6 volumes, which consist of 1 part of oxygen and 2 parts of chlorine, the oxygen in the protoxide being condensed into one half its bulk. Hence its constitution may be expressed as follows.

			Prop.			Atoms.		Weight.
Chlorine	-	-	1	-	-	1	-	81.72.
Oxygen	-	-	1	-	-	1	-	22.28.
			<hr/>			<hr/>		<hr/>
			2			2		100.00

And the number representing the protoxide will be $83.5 + 7.5 = 41$.

2. Deutoxide of Chlorine.

CCLXXI. This gas was discovered in 1815, about the same time by Sir H. Davy and Count Von Stadion of Vienna. The analyses of the gas by these two chemists do not correspond, and if both be correct, they must be the results of experiments upon different gases. But the modes employed for obtaining them were the same, and the important properties of both are described as being similar. It is most probable, therefore, that they operated upon the same compound. According to the process of Sir H. Davy, a quantity of powdered chlorate, or hyper-oxy muriate of potash is made into a solid mass with sulphuric acid, which is put into a small retort connected with a mercurial apparatus, the body of the vessel is then exposed

to heat, taking care that it does not rise so high as 212° ; a yellow coloured gas is slowly produced which passes over into the receiver.*

When the acid is mixed with the salt, the mass becomes yellow, and care should be taken to form the mixture with small quantities at a time; otherwise the salt decrepitates, and particles of the acid are thrown to some distance.

Count Stadion obtained the deutoxide, by fusing a quantity of the chlorate of potash in a small retort, allowing it to cool, and then pouring upon it concentrated sulphuric acid. The body of the retort was afterwards exposed for three hours to the heat of a water bath gradually raised from $54^{\circ}.5$ to 212° .† It is obvious that this process is essentially the same as that of Sir H. Davy's, the previous fusion of the salt having had no other effect than to drive off its water of crystallization.

Deutoxide of chlorine is permanently elastic, and has a more intensely yellowish green colour than the protoxide. Its odour is peculiar, differing from that of chlorine, and it irritates the eyes when exposed to it, almost like ammonia. Water absorbs at least seven times its volume of this gas, the solution is of a lemon colour, it has a pungent and peculiar taste, and when preserved from light experiences no change. When exposed to the solar rays, it is decomposed, it loses colour and the gas is converted into chlorine and chloric acid. When heat is applied to the solution, chlorine is evolved, and chloric acid remains dissolved in the water.

This gas produces no change in blue vegetable colours, nor does it act upon mercury. It may be preserved in the dark, if it be not in contact with combustible or alkaline bodies, but exposed to direct solar light, it is decomposed and converted into chlorine and oxygen gases. The same effect is produced more rapidly by heat and electricity. When raised to a temperature between 112° and 144° , it explodes; the explosion is more violent than that of the protoxide, and

*Annals of Philosophy, vol. vii. p. 28.

† Ibid, vol. ix. p. 22.

two volumes become three, which consist of one of chlorine and two of oxygen. Hence it follows, according to this analysis of Sir H. Davy, that the deutoxide is composed of

		Prop.			Atoms.		Weight.
Chlorine	-	1	-	-	1	-	53.07
Oxygen	-	4	-	-	4	-	46.93
		<hr/>			<hr/>		<hr/>
		5			5		100.00

and it must be represented by $33.5 + 30$, or 63.5 . It does not act at common temperatures upon any of the combustible substances, except phosphorus, which when introduced into the gas produces an explosion, and burns with great brilliancy.

Count Stadion found that when the gas which he discovered was exploded over mercury, the chlorine was absorbed, and oxygen equal in bulk to the gas was left in the tube; and by subsequent experiments he proved that the results of its decomposition were two volumes chlorine and three of oxygen. These would make it consist of one proportion of chlorine and three of oxygen; and its representative number would be $33.5 + 22.5$ or 56 .

3. *Chloric acid.*

CCLXXII. Chloric acid was discovered by M. Gay-Lussac. It is prepared by pouring into a diluted solution of the salt called oxy-muriate of barytes, drop by drop, weak sulphuric acid. A decomposition of the salt takes place, sulphate of barytes is separated, and the chloric acid remains in the liquid. If sulphuric acid be not added in excess, the liquid after the process will be free from that acid and barytes, and will afford no precipitate with nitrate of silver.*

Chloric acid is in the form of a colourless and transparent liquid, destitute of smell, but having a very acid taste, and it reddens without destroying vegetable blues. It produces no change on solution of indigo in sulphuric acid; nor is it affected by light, or by exposure to atmospheric air. It

* Memoir on Iodine. *Annals of Philosophy*, vol. vi. p. 128.

may be concentrated by a gentle heat, without evaporating or undergoing decomposition, and it then acquires an oily consistency. When exposed to heat it is partly decomposed, yielding chlorine and oxygen, and partly volatilized without alteration. It is decomposed in the same way by muriatic acid even at common temperatures. It combines with the salefiable bases and forms salts which are called *chlorates*. This compound appears to be the same as the hyper-oxy-muriatic acid of Mr. Chenevix, and makes a component part of the hyper-oxy-muriates.

The composition of chloric acid may be determined by the decomposition of the salt chlorate of potash; 100 parts when exposed to heat yield 38.88 of oxygen and 61.12 of chloride of potassium, which is composed of 28.924 of chlorine, and 32.196 of metal. But 32.196 of potassium require 6.576 of oxygen to form potash; and hence there will remain 32.304 of oxygen to convert the 28.924 of chlorine into chloric acid. Now $28.924 : 32.304 :: 47.24 : 52.76$, and chloric acid will be constituted as follows.

		Prop.		Atoms.			Weight.
Chlorine	-	1	-	1	-	-	47.24.
Oxygen	-	5	-	5	-	-	52.76.
		<hr/> 6		<hr/> 6			<hr/> 100.00.

The number representing chloric acid is 71.

As this acid contains five times as much oxygen as the protoxide of chlorine, which is so easily decomposed, it is inferred by M. Gay-Lussac, that its elements are kept united by the water with which it is combined; and that liquid is presumed to act the part of a base, as in the case of the nitric and sulphuric acids.

4. *Perchloric acid.*

CCLXXIII. After the action which produces the deutoxide of chlorine has ceased, there remains in the vessel a peculiar salt,

one of the constituents of which is the acid above mentioned. The salt is best obtained by adding three or four grains of strong sulphuric acid to each grain of the chlorate of potash employed. When the violent action between the materials has subsided, heat is to be applied and continued until the yellow colour of the mass disappears. The salt formed in this way is mixed with *bi-sulphate* of potash, from which it may be freed by solution and subsequent crystallization.

It is a neutral salt, possessing a weak taste similar to that of muriate of potash, it is not altered on exposure to the air. It is susceptible of crystallization, and the form which it assumes appears to be the octoedron, and to belong to the variety distinguished by Haüy under the name of *plomb sulfaté semi-prismé*. Water at the temperature of 60° takes up only $\frac{1}{3}$ of its weight, but it is much more soluble in this liquid at 212° . It is insoluble in alcohol. It detonates feebly when triturated in a mortar with sulphur. At the temperature of 412° , it is decomposed and converted into chloride of potassium and oxygen gas. When mixed with an equal weight of sulphuric acid and exposed in a retort to a heat of 280° , it is decomposed, an acid is disengaged and distils into the receiver. The same acid may be formed directly by exposing the deutoxide of chlorine to the action of voltaic electricity in an apparatus, the conducting wires of which are of platina.*

We have no account of the properties of this acid.

From the experiments of Count Stadion, by whom it was discovered, it appears that by the decomposition of this salt there are obtained 45.92 parts of oxygen, and 54.08 parts of chloride of potassium, which chloride is composed of 25.60 of chlorine and 28.48 of potassium. Now deducting 5.819 parts of oxygen required by 28.48 parts of potassium to be converted into potash, the quantity of oxygen obtained and necessary to the constitution of the acid will be 40.10 parts. Hence $25.60 : 40.10 :: 38.97 : 61.03$, and the oxy-chloric acid

* Annals of Philosophy, vol. ix. p. 23.

of Count Stadion, or the perchloric acid of Dr. Thomson will be composed of

		Prop.			Atoms.		Weight.
Chlorine	-	1	-	-	1	-	38.97.
Oxygen	-	7	-	-	7	-	61.08.
		<hr/>			<hr/>		<hr/>
		8			8		100.00.

and it will be represented by $33.5 + 52.5$, or 86.

From the difficulty of operating upon the gaseous compounds of chlorine and oxygen, the distinction between the protoxide and deutoxide of chlorine does not appear to be demonstrated. Sir H. Davy is now inclined to the opinion that what he first obtained and described as euchlorine gas was a mixture of chlorine and the deutoxide. It is questionable, therefore, whether it have a separate existence, but as further experiments are required to ascertain this point, it may be at present described as a distinct compound.

The principal and most important use to which chlorine is applied, is that of removing the colour of cloths, and it is extensively employed in the art of bleaching. It has also been strongly recommended by M. Guyton Morveau as a valuable substance for fumigating infected apartments.

SECTION III.

Iodine.

CCLXXIV. This singular substance was discovered in 1811, and partially examined by M. Courtois, a manufacturer of salt-petre at Paris. A quantity of it was given by him to M. Clement, who presented an account of some of its properties to the National Institute in December 1813. Soon afterwards, an examination of iodine was undertaken by Vauquelin, which was followed by the researches of M. Gay-Lussac. At this time, Sir H. Davy being in Paris received some of it

from M. Ampère; he investigated its nature and properties, and the results were published in the *Philosophical Transactions* for 1814.

The researches of these philosophers unfolded many of the facts connected with iodine, and they were subsequently developed with great precision by M. Gay-Lussac, whose admirable memoir was published in the *Annales de Chimie*. This chemist gave to it the name of *Iode*, which was changed by Sir H. Davy to *Iodine*, as being more conformable with the idiom of the English language.

CCLXXV. Iodine may be obtained by two methods, from the kelp, black-ash, or barilla of commerce. The French barilla is said to yield the largest product.

1. This mass is to be steeped in water until the whole of the soluble part is extracted. The solution, after being filtered, is gently evaporated in a basin of Wedgewood's ware, and the evaporation is to be continued until crystals cease to be deposited. The crystals are removed as they are formed. The mother-water, as it is called, is then evaporated to dryness, the solid saline mass obtained is melted, and when cool is reduced to a coarse powder, which is put into a deep tubulated retort connected with a large globular receiver. When highly concentrated sulphuric acid is poured upon the salt, and a gentle heat is applied, a brisk effervescence takes place, a vapour of a beautiful violet colour rises, which soon condenses in crystals in the neck of the retort. This substance is to be washed out with the smallest possible quantity of water, dried quickly on bibulous paper, and immediately inclosed in a glass phial.

2. Dissolve kelp, or barilla in water, concentrate the solution by evaporation, and separate the crystals; the remaining liquid is to be put into a clean vessel, mixed with an excess of sulphuric acid, and boiled for some time; sulphur will be deposited and muriatic acid disengaged. The liquid is then to be strained through wool; it is afterwards put into a flask, finely powdered black oxide of manganese. equal in

weight to the sulphuric acid employed, is added, and a glass tube 12 or 15 inches in length and open only at one end is fitted to the mouth of the flask. By the application of a gentle heat, the iodine rises in vapour, and condenses upon the internal surface of the tube. This method was first practised by Dr. Wollaston, and it furnishes a larger product than the one first described. Whichever mode, however, be employed, it will be necessary to make use of large quantities of the kelp or barilla.

CCLXXVI. In its solid state, iodine has the colour and lustre of plumbago or black lead. It usually appears in the form of scales, and may be obtained in large and brilliant rhomboidal plates. It is also obtained in crystals, the form which is an octoedron, whose axes, according to Dr. Wollaston, are in the ratio to each other of 2, 3, and 4. These crystals are sometimes an inch in length.

The fracture of iodine is lamellated; it has a fatty lustre; is very soft and friable, and it may be rubbed to a fine powder. It evaporates on exposure to the air. Its taste is acid, and it exhales the same odour, though in a less degree, as that of chlorine. When applied to the skin it produces a deep brown stain, which however is soon removed. Like chlorine it possesses the property of discharging vegetable colours, but with much less energy.

The specific gravity of iodine at $62\frac{1}{2}^{\circ}$, according to M. Gay-Lussac is 4.948. Exposed to heat it melts at the temperature $224^{\circ}.5$, and is volatilized, under mean pressure, between 347° and 356° . The colour of its vapour is a beautiful violet; hence the name of iodine, from *ἰωδης*, *violaceous*. From the experiments of M. Gay-Lussac, it appears that this vapour has a greater density than that of any other substance with which chemists are acquainted; its ratio to that of oxygen being as 15.621 to 1; and it is 117.71 times heavier than an equal volume of hydrogen. The last number then represents the proportion of iodine, hydrogen being unity.

CCLXXVII. Iodine is very sparingly soluble in water, requiring for its solution 7000 times its weight of that liquid.

The solution is of an orange yellow colour. It is more soluble in alcohol, and in still larger proportion in sulphuric ether. When mixed with water, it may be distilled over at 212° . This fact, however, is no proof that iodine is capable of volatilization at that temperature; for the same circumstance, as remarked by Gay-Lussac, happens with the essential oils when distilled with water, although when unmixed they boil only at or about 309° . Iodine is a non-conductor of electricity. It has never been decomposed, and must therefore be considered as a simple, or undecomposed body.

There is but one substance, which, during its combination with iodine, exhibits the phenomenon of flame; this is the metal called potassium, the basis of potash. When the vapour of iodine is passed over potassium previously heated in a glass tube, the latter takes fire and burns with a pale blue flame, and the product is a compound of the two substances. With other bodies, though iodine in combining produces heat, yet no light is visible. If a quantity of iodine be put into a glass tube sealed at one end, and phosphorus be added, a rapid combination will take place, and the temperature will proportionally rise. Combinations may also be effected between iodine, sulphur, and most of the metals; and these binary compounds are known by the names of *iodides*. Gay-Lussac calls them *iodurets*.

Iodine is capable of combining with oxygen and chlorine; forming with the first the *Oxiiodic acid*; and with the second the *Chloriodic acid*.

Iodic or Oxiiodic acid.

CCLXXVIII. Although M. Gay-Lussac failed in his attempts to obtain the acid compound of iodine and oxygen, yet he investigated its combinations, and even succeeded in stating the proportions of its elements. The iodic acid was first procured by Sir H. Davy, by causing a current of protoxide of chlorine to act upon iodine. About 100 grains of chlorate of potash

are put into a bent tube open only at one end, and upon the salt are to be poured 400 grains of muriatic acid of the specific gravity of 1.105. To the mouth of the tube is adapted a second, bent at a right angle, and containing fused muriate of lime, and terminating in a small long-necked receiver, into which have been previously introduced about 40 grains of iodine. A gentle heat is to be applied, protoxide of chlorine forms, which after being deprived of its water by the salt of lime comes into contact and combines with the iodine, producing two compounds, one of oxygen and iodine, the other of chlorine and iodine. When these products are exposed to heat, the chloride of iodine being volatile is evaporated, while the other compound remains behind in a state of purity. This constitutes the iodic acid.

CCLXXIX. It is a white solid, semi-transparent, destitute of smell, and of considerable specific gravity, sinking rapidly in sulphuric acid. Its taste is astringent, and in water, sour. It dissolves rapidly in this liquid, forming a colourless solution, possessing acid properties. It first reddens, and then destroys vegetable colours. Submitted to a temperature little short of the boiling point of olive oil it melts, and is then decomposed into oxygen and the vapour of iodine. When exposed to the air, iodic acid is slightly deliquescent; its aqueous solution may be evaporated without decomposing the compound, it first acquires the consistence of syrup, then becomes pasty, and finally the acid is obtained dry and pure. It exerts a strong action upon combustible bases. When heated with sulphur, carbon, sugar, resins, or some of the metals in a state of minute division, it occasions explosions. Its solutions rapidly corrode metallic bodies. It combines with the salefiable bases, forming salts called *iodates*. These salts when in the neutral state are but little soluble.

One hundred parts of dry iodate of potash produce, when decomposed by heat, 22.59 parts of oxygen, and 77.41 of iodide of potassium, which salt contains 58.937 of iodine, and 18.473 of potassium; but 18.473 of potassium require, in or-

der to be converted into potash, 3.773 of oxygen; hence the 58.937 parts of iodine are combined with 18.817 of oxygen to form the acid.* Now $58.937 : 18.817 :: 75.80 : 24.20$; and the composition of the Iodic acid may be expressed in the following terms.

		Atoms.			Prop.		Weight.
Iodine	-	1	-	-	1	-	75.80
Oxygen	-	5	-	-	5	-	24.20
		<hr/>			<hr/>		<hr/>
		6			6		100.00

It must be represented by $117.7 + 37.5$, or 155.2 .

Sir H. Davy states the proportions of the elements in Iodic acid by weight at 81.28 of iodine and 18.72 of oxygen; in this case it will be composed of 1 proportion of the former, and 4 proportions of the latter, and its representative number will be $117.7 + 30 = 147.7$.

Chloriodic acid.

CCLXXX. When dry iodine and chlorine are brought into contact, a rapid combination takes place, and the temperature rises to 212° . Two compounds appear to be formed, the one exhibiting a fine orange yellow, and the other an orange red colour. These compounds were considered by M. Gay-Lussac as chlorides; the last he called chloruret, and the first sub-chloruret of iodine. The latter contains less chlorine than the former, and is more volatile. Both of these compounds deliquesce on exposure to the air. They are soluble in water, the solution of the *sub-chloruret* being of a deeper orange yellow the more iodine it contains. The solution of the *chloruret* is colourless when the excess of chlorine is driven off, and the mutual saturation of the two elements then appears complete. The solutions of both are very acid, and they destroy the colour of solution of indigo in sulphuric acid. When a solution of alkali is added to that of the chloruret, the

* Gay-Lussac.—Memoir on Iodine.

latter is converted into iodic and muriatic acids, and combines with the base to form an iodate and chloride. Heat disengages chlorine from the solution of the chloruret, and changes it into a sub-chloruret. The solution of the last compound is volatilized without decomposition. If an alkali be cautiously added to it iodine is precipitated, by which character it is distinguished from the chloruret.

The chloruret is obtained in the solid state with great difficulty, but its solution is easily formed in water, by saturating a solution of sub-chloruret with iodine, and exposing it to light until it loses its colour.

These chlorurets are inferred by M. Gay-Lussac to decompose water, the iodine combines with the oxygen, to form iodic acid, and the chlorine with the hydrogen to compose muriatic acid. But the hypothesis might be supported either that the elements still preserve their properties unchanged, as they act upon indigo; or that when united they constitute a peculiar acid, which is decomposed when saturated with a base, for example, an alkali.*

Upon the supposition that these compounds are chlorides of iodine, the protochloride, or orange red compound, will consist of 1 proportion of iodine 117, and 1 of chlorine 33.5; and the deutochloride, or orange yellow, of 1 proportion of iodine 117, and 2 proportions of chlorine 67.

Sir Humphry Davy considers the compound of iodine and chlorine, formed by the method above mentioned, as an acid, and has given to it the name of chloriodic acid. He infers that its elements exist in equal proportions. Dr. Thomson on the contrary thinks it to be composed of 1 atom of iodine and 2 atoms of chlorine.†

CCLXXXI. The solution of iodine rapidly corrodes metallic bodies; hence silver has been proposed by Sir H. Davy as a substance well calculated to discover the presence of iodine. A polished plate of this metal soon becomes tarnished on being immersed in any liquid containing this element.

* Annals of Philosophy, vol. v. p. 296.

† System of Chemistry, vol. i. p. 199. 5th ed.

M. M. Colin and Gaultier de Claubry discovered that iodine is capable of forming a compound with starch, which exhibits a fine blue colour. This compound may be produced by triturating starch with an excess of iodine, dissolving the mixture in solution of potash and decomposing it by a vegetable acid. The iodide falls down in the form of a fine blue powder. Starch is a very delicate test of the presence of iodine in liquids; and it is affirmed by Stromeyer that it assumes a perceptible blue tinge when the iodine exists in no larger proportion than $\frac{1}{430,000}$ part. If a liquid containing iodine be brought into contact with common paper, it produces a blue tinge.

M. De Claubry has examined sea-water for the purpose of ascertaining whether it contains iodine, but no trace of it could be discovered. It was found by him to exist in the following marine plants of the genus *Fucus*; *f. saccharinus*, *digitatus*, *vesiculosus*, *siliquosus*, *filum*.* It was also discovered in small proportion by Sir H. Davy, in the ashes of the *fucus cartilagineus*, *membranaceus*, *rubens*, *filamentosus*, *ulva pavonia*, and *ulva linza*.†

I have found the kelp manufactured in the District of Maine much richer in iodine than the barilla imported from the Mediterranean. This kelp has a colour formed of shades of grey and yellow.

“It would appear that chlorine, oxygen, and iodine separate each other from bases at a red heat in the following order;

Chlorine

Oxygen

Iodine.

Chlorine drives off the other two, while oxygen disengages iodine. Hence, according to the present language of chemistry, chlorine has the greatest *affinity* for the bases, oxygen the next greatest, and iodine the weakest. But to this

* *Annals of Philosophy*, vol. vii. p. 30 † *Philos. Trans.* for 1814.

rule there are many exceptions. Thus iodine disengages oxygen from potassium and sodium at a red heat.”*

CCLXXXII. Although the claims of Iodine to be considered as a supporter of combustion, according to the common acceptance of that term, are not very strong, yet from its other properties may be derived a sufficient reason for placing it in the same class with oxygen and next to chlorine. It is a non-conductor of electricity, and possesses the negative electrical energy with respect to metals, inflammables, and alkaline substances; and hence, when combined with these substances in aqueous solutions, and electrized in the voltaic circuit, it separates at the positive surface. It agrees with chlorine in forming an acid with hydrogen, and with oxygen in producing an acid with chlorine. That it produces so little heat, and so seldom light in entering into combination, may be accounted for from its solid form, and its great weight as an element. Potassium however burns in its violet coloured gas, and when this gas is thrown upon the flame of hydrogen, it seems to support its combustion.†

M. Gay-Lussac favours the opinion that iodine is analogous to chlorine and sulphur; thus sulphur takes oxygen from iodine, and iodine takes it from chlorine; but on the other hand, chlorine takes hydrogen from iodine, and iodine from sulphur. Iodine also resembles the two other elements in forming two acids, one with oxygen, the other with hydrogen; and there is a resemblance between the iodates and chlorates, but a much greater analogy between the iodates and the sulphates.‡

Iodine may perhaps be considered as a connecting link between the preceding elements and the combustible and acidifiable bases.

* Dr. Thomson.—System of Chemistry, vol. i. p. 200. 5th ed.

† Davy.—Philosophical Transactions for 1814.

‡ On Iodine.—Translated. Annals of Philosophy, vol. v. p. 412.

SECTION IV.

Fluorine.

CCLXXXIII. There exists in nature a mineral called fluor spar, which is usually crystallized in cubes, and displays a great variety of colours in which the purple usually predominates. It is found in abundance in Derbyshire in England, and in consequence of its beauty is manufactured into ornaments of different kinds. Mr. Scheele first pointed out in 1771 the method of decomposing this compound. He proved that it consisted of lime and a peculiar acid, to which he gave the name of Fluoric acid. Few substances have been submitted to a more rigorous chemical investigation. This acid and its compounds have been made the subjects of research by Dr. Priestley, Wiegleb, Bucholtz, Meyer, Dr. John Davy, M. M. Gay-Lussac and Thenard, and Sir Humphry Davy. The fluoric acid, as obtained by the method of Scheele, was proved to contain silica, and it was not until 1811, that the mode of procuring it in a pure state was discovered by M. M. Gay-Lussac and Thenard.

White Fluuate of lime, free from silica, is to be powdered and put into a leaden retort, which should consist of two pieces fitted into each other for the purpose of facilitating the extraction of the residue of the operation. Double the weight of strong sulphuric acid is added, the beak of the retort is then introduced into a receiver, or tube of the same metal, surrounded with ice or cold water, the joinings are to be carefully luted, and the body of the retort is to be exposed to a moderate heat. An ebullition is heard, which is occasioned by the disengagement of the fluoric acid, and the operation is finished, when on withdrawing and cooling the neck of the recipient, no traces of a liquid are perceptible. Great caution is necessary in conducting this process, for the acid is exceedingly corrosive; hence if the vapour at any part of the process should escape from the joinings, no attempt should be made to renew

the lute, and the operation must be stopped. The hands and face in fact should be protected from the immediate action of the acid by appropriate coverings.

The lead of which the vessels are formed should be pure.

CCLXXXIV. Fluoric acid, thus obtained, is a transparent and colourless liquid, which is not altered by exposure to a cold equal to -4° Fah. Its boiling point is unknown, but it preserves the liquid state at 60° . It is very volatile, and on exposure to the air rapidly evaporates. Hence it is necessary to preserve it from the atmosphere, and for this purpose vessels of lead or silver must be employed, for such is the activity of fluoric acid, that it acts upon all other bodies. While evaporating, copious white fumes are produced, the odour of which is similar to, but much stronger than that of muriatic acid. These fumes are corrosive. One of the most extraordinary properties of this acid is its action upon the skin. However small the quantity may be, as soon as it comes into contact with the body, it immediately kills and disorganizes the part, producing painful blisters which terminate in suppuration. The inflammation even extends to some distance, and occasions much constitutional irritation. Some remarkable instances are mentioned by M. M. Gay-Lussac and Thenard, of the prodigious activity of this acid in its purest state,* and these chemists themselves, notwithstanding their precautions, suffered severely from its caustic quality.

When dropped into water, a violent action takes place accompanied with a hissing noise similar to that produced by a red hot iron; if the water be added to the acid, so much heat is produced as to cause it to boil; and it may be very considerably diluted in this way without losing its fuming property. When combined with a certain quantity of water its specific gravity is 1.25. In its pure state it is said by Sir H. Davy to be free from water and its specific gravity is then 1.0609.

Fluoric acid combines with the salefiable bases and forms salts, which are called *fluates*.

* *Rechères Physico-chimiques*, t. ii. p. 11.

This acid does not exist abundantly in nature. The principal compound in which it is found is the fluor spar or fluato of lime; Klaproth, however, discovered it in the Sazon topaz, and Vauquelin in the topaz from Brazil. The mineral called wavellite, according to Sir H. Davy, contains a small proportion, and M. Gay-Lussac found it in ivory. Morrichini asserts that it forms a constituent part of the enamel of human teeth, but the fact is denied by Mr. Brande.

CCLXXXV. Notwithstanding the refined and able researches of M. M. Gay-Lussac and Thenard and of Sir H. Davy, such is the powerful affinity which operates in combining the elements of the fluoric acid, that great uncertainty still exists respecting the nature of its base, and the substance which gives it acid properties.

In the years 1808 and 1809, after the discovery of potassium by Sir H. Davy, M. M. Gay-Lussac and Thenard made use of that inflammable metal with a view of decomposing fluoric acid.* They obtained some favourable results, by heating it in contact with the gas which is produced when fluoric acid acts upon glass. This gas is the silicated fluoric acid, resulting from the combination of the fluoric acid with the silica which enters into the composition of vitreous compounds. Combustion took place, the gas was absorbed, hydrogen was disengaged and the potassium disappeared. The product was a solid of a reddish or chocolate brown colour, which, on exposure to water, produced slowly a quantity of hydrogen not more than $\frac{1}{3}$ of the amount which would have been disengaged by the action of pure potassium. The water after the experiment was found to be a solution of fluato of potash with an excess of alkali. There remained undissolved a substance of a reddish brown colour which, on being heated in oxygen gas, burned vividly and formed a solid fluato of potash and silica. From these facts the conclusion was drawn that the potassium had probably decomposed the fluoric acid; that a fluuret of potash had been formed which decomposed

* *Rechères*, t. ii. p. 65.

the water, and disengaged its hydrogen; and that one of the products might have been a fluuret of potash and silica, which at a high temperature and in contact with the air might have burnt and have passed to the state of a fluete.*

CCLXXXVI. At this period or immediately after, Sir H. Davy was employed in researches of the same nature. By means of potassium, a substance of a chocolate colour was obtained, which when acted upon by water produced an inflammable gas of a peculiar odour; heated in contact with common air or oxygen gas, it burned and formed a white acid substance. The acid was therefore probably decomposed, but the radical was not obtained in sufficient quantity to enable him to ascertain its properties with precision; nor was he more successful in attempting to obtain it by the agency of voltaic electricity; for although hydrogen was disengaged at the negative and the brown substance at the positive pole, it was in too minute a quantity to be accurately examined.

CCLXXXVII. There appears to be sufficient evidence that fluoric acid is a compound and that its radical is unmetallic, but highly inflammable. Does it owe its acid properties to the presence of oxygen or of hydrogen? M. M. Gay-Lussac and Thenard favour the first opinion; but Sir H. Davy has adopted the idea of M. Ampère, that an analogy in properties exists between this compound and muriatic acid, which is composed of equal volumes of chlorine and hydrogen. Upon this hypothesis the radical of the fluoric acid, which has been called by Sir H. Davy, fluorine, is combined with hydrogen. The arguments in its favour are, 1. That liquid fluoric acid in its combinations with ammonia does not, like all the acids which contain oxygen, disengage water. 2. That when fluete of ammonia and potassium are heated in contact, fluete of potash is formed and there are evolved ammoniacal and hydrogen gases in the proportion of 2 volumes of the former to 1 volume of the latter. These results appear to

* *Rechères*, t. ii. p. 69.

favour the idea that fluato of potash is a compound of potassium and the radical of the fluoric acid, the hydrogen being derived from the decomposition of that acid. 3. That in the decomposition of fluoric acid by electricity, hydrogen is disengaged at the negative and a chocolate substance at the positive wire. All these facts show an analogy to exist between fluoric and muriatic acids.* If this hypothesis be adopted the fluates must be considered as fluorides or binary compounds of the bases with the fluoric radical.

It must be acknowledged however, that much obscurity still hangs over this subject; and that researches are still wanting to develop the true nature of fluoric acid. So far however as we have learnt, the properties of the basis of this acid are more analogous to the class of bodies which have been described than to any other, and hence it has been ranked among them.

* Phil. Trans. for 1813.



CHAPTER II.

OF THE UNDECOMPOUNDED INFLAMMABLE OR ACIDIFIABLE,
UNMETALLIC BODIES ; AND OF THEIR COMBINATIONS WITH
THE SUPPORTERS OF COMBUSTION AND WITH EACH OTHER.

CCLXXXVIII. The simple elementary substances, which are included in this class, amount to seven. They are hydrogen, nitrogen, boron, silicon, sulphur, carbon, and phosphorus. They will be described in the order of their attraction for oxygen. It is not easy, however, to determine this order, for the forces of affinity vary with the temperature, and the decompositions by which the relative attraction is to be determined are often reciprocal. Charcoal at a red heat decomposes water, and its affinity for oxygen in this instance is greater than that of hydrogen, but on the other hand hydrogen at the same temperature takes oxygen from carbon, or decomposes carbonic acid, and here its attraction for that element is superior to that of carbon. Sir H. Davy from his observations arranges them in the following manner, hydrogen, boron, carbon, phosphorus, sulphur, nitrogen.*

Dr. Thomson places hydrogen before carbon, because when carburetted hydrogen is mixed with an under proportion of oxygen and fired by electricity, the hydrogen combines with the oxygen in preference to the carbon.

Phosphorus is placed after carbon, because it does not, like that element, seem capable of decomposing water, and because its action upon carbonic acid requires to be facilitated by the presence of a base. Sulphur does not seem capable of decomposing phosphoric acid. but phosphorus acts to a certain extent upon sulphuric acid. Sulphur is known to decompose nitric acid, at least partially ; but azote has no sensible action upon sulphuric acid.† Nitrogen or azote is placed by M. Gay-Lussac in the same class with oxygen, iodine and sul-

* Elements of Chem Philos. part i. p. 497.

† System of Chemistry, vol. iii. p. 145. 5th ed.

phur, and the analogies are stated which led him to this view of its relations.* The attraction of silicon for oxygen appears to be stronger than that of boron. Their compounds with oxygen are both decomposed by potassium and carbon; but boron is obtained in larger quantities and with greater facility than silicon. The properties of the former have been examined with considerable accuracy, but those of the latter are still but imperfectly known. The affinity of nitrogen for oxygen is comparatively feeble and there is no oxide, or compound of a base with oxygen, which it is capable of decomposing; it ought therefore to be placed the last in the table; but it will perhaps be allowable to depart in this instance from the order of attraction, and to rank it next to hydrogen; because the compounds which it forms with oxygen are very important and require to be known at an early period in the description of this class of bodies. I shall therefore describe them in the following order.

Hydrogen	Carbon
Nitrogen	Phosphorus
Silicon	Sulphur.
Boron	

* Annals of Philosophy, vol. v. p. 412:

SECTION I.

Hydrogen.

CCLXXXIX. This element in its uncombined state exists in the elastic form. It was known to the earlier chemists and Van Helmont gave it the name of gas Igneum or Sylvestre. Its properties were first accurately examined in 1766 by Mr. Cavendish and they were afterwards fully investigated by Priestley, Scheele, Sennebier and Volta. It was at first known by the name of inflammable air, which was subsequently changed by the French chemists to hydrogen, from *ὕδωρ*, water and *γενέσθαι*, I produce.

Hydrogen may be obtained by partly filling a gun-barrel with iron wire or turnings and laying it across a furnace; to one end is fitted a retort containing water and to the other a tube leading into a gazometer or hydro-pneumatic apparatus. When the barrel is heated red hot, the water in the retort is made to boil, and its vapour, in passing over the ignited surfaces of the iron, is decomposed and large quantities of gas pass into the receiver. A more convenient and less laborious method is to put into a tubulated retort one part of iron or zinc filings, and to add to it two parts of sulphuric acid diluted with 3 or 4 times its bulk of water; an effervescence immediately takes place, hydrogen gas is disengaged, and after the atmospheric air is pressed out, the beak of the retort may be placed under the receiver.

Hydrogen obtained by either of these methods is impure, and according to Mr. Donovan requires to be submitted to certain processes in order to be entirely freed from foreign matter. He prepared the gas from zinc and iron, acted upon by diluted sulphuric or muriatic acid. By passing it through caustic ammonia, he obtained traces of sulphuretted hydrogen, while lime-water retained a small portion of sulphur. When purified in this way, it had exactly the smell of phosphorus,

and burned with a green flame. Upon the supposition that it might contain phosphorus, it was made to pass through four of Woulf's bottles, the first of which contained lime-water, the second nitrous acid, the third water, and the fourth solution of sulphate of iron. Purified in this manner, hydrogen had no smell, and gave so little light while burning, that the colour of the flame could not be determined.*

CCXC. Hydrogen is a permanently elastic, invisible fluid, susceptible of indefinite compression and dilatation. In its pure state it is inodorous, but as commonly procured it has a disagreeable smell, which has been attributed to the presence of water, for when dried by muriate of lime, it loses its peculiar odour. It is the lightest of all bodies, the weights of which are capable of being estimated. Its specific gravity compared with that of atmospheric air is as 0.0732 to 1.0000; and with that of oxygen gas as 1 to 15. An hundred cubic inches, at the temperature of 60° and under mean atmospheric pressure, weigh only 2.23 grains. The specific heat of hydrogen gas is greater than that of any other substance, at least in equal weights; according to the experiments of M. M. Berard and De la Roche it is in the ratio to atmospheric air of 12.3401 to 1.0000; in equal volumes the ratio is as 0.9033 : 1.0000. The weight of its atom is calculated by Dr. Thomson to be 1.25. Its proportion is represented by 1, or unity.

This gas is incapable of supporting combustion, or respiration. When a vessel containing hydrogen is brought with its mouth downward over a lighted candle, the flame is extinguished, but the stratum of gas in contact with the atmosphere takes fire. When breathed by animals it appears to destroy life, rather by the exclusion of oxygen than by any positive or specific action exerted by it upon the system. Hydrogen is not absorbed in any quantity by water. If the liquid have been previously boiled, it takes up according to Dr.

* Annals of Philosophy, vol. xii. p. 12.

Henry 1.53 inches of the gas; but Saussure Jun. affirms that it will absorb 4.6 cubic inches; and alcohol 5.1 inches.

CCXCI. Hydrogen gas is highly inflammable. When a flame is applied to the mouth of a vessel containing it and open to the atmosphere, it takes fire and burns with an attenuated lambent flame of a reddish yellow colour. It is also inflamed by an iron wire heated fully red, and the temperature necessary to its inflammation has been estimated by Dr. Thomson at about 1000° . If it be previously mixed with atmospheric air in the proportion of equal volumes, and a flame be applied, combination takes place so rapidly as to produce an explosion. If instead of common air pure oxygen be substituted, and the gases be mixed in the ratio of 2 volumes of hydrogen to 1 volume of oxygen, the explosion will be much more violent.

If this explosion be conducted in an eudiometric tube standing over mercury, by transmitting through the mixture an electrical spark, the whole will be condensed, the mercury will rise in the vessel, and the only product of the operation will be *water*.

Water.

CCXCII. Until about the year 1780 this liquid was considered as an element. The merit of having first demonstrated its composition is due to Mr. Cavendish, who obtained it by burning hydrogen in atmospheric air. Lavoisier a short time afterwards succeeded in producing it by the same method, and the subsequent experiments of the French chemists between the years 1780 and 1788 placed the fact beyond doubt, that water is a compound of hydrogen and oxygen. Among others, Le Fevre de Gineau consumed 2 pounds, 3 ounces, 63.8 grains of the gases, and obtained as the only product a quantity of water amounting in weight to 2 pounds, 3 ounces and 33 grains; hence there was a deficit of only 30.8 grains, which was accounted for from the difficulty of

estimating with the necessary exactness the precise weights of the gases. The most accurate of the experiments to ascertain the composition of water synthetically, was made by Fourcroy, Vanquelin, and Seguin. The number of cubic inches of hydrogen combined amounted to 25963.563, and that of oxygen to 12570.942 inches, weighing in all 7249.22 grains, and the weight of the water formed was equal to 7245 grains; and there was a loss, therefore, of only 4.227 grains. This water was examined by four eminent French philosophers, Lavoisier, Brisson, Meusnier and La Place. It was not sensibly acid, and it produced no precipitate with nitrate of lime; its specific gravity, compared with that of distilled water, was as 18671 to 18670. It was therefore pure.

CCXCIII. If water be a compound, it is obvious that its elements may be obtained by subjecting it to an affinity more powerful than that which combines the oxygen and hydrogen, or in other words it may be decomposed, if a substance can be found, the attraction of which for one of the elements is greater than prevails in the existing compound. Hence, when the vapour of water is transmitted over the ignited surfaces of iron, it disappears, the metal increases in weight and is altered in properties, and hydrogen gas is obtained in the receiver. The weight of this gas, added to the weight gained by the iron, is just equal to that of the water which has been expended. The iron is found in the state of oxide. When iron or zinc is exposed to the action of diluted sulphuric acid, hydrogen gas is disengaged, and the metal is procured in combination with oxygen. As the acid employed is capable of saturating the same weight of alkali at the conclusion of the experiment as before, it could not have furnished the oxygen united with the metal; it must, therefore, have been derived from the water while its other constituent, the hydrogen, was disengaged in its gaseous state. When pure water, which has been freed by boiling from atmospheric air, is electrified from platina wires in the voltaic circuit, oxygen gas rises from the positive and hydrogen gas from the negative pole,

and always in the same proportion, viz. 1 volume of the former to 2 volumes of the latter. If the gases thus obtained be mingled and then exposed to the electric spark, an explosion takes place, and they are totally condensed into water. It appears therefore, from a multitude of synthetical and analytical experiments, that water is a compound of oxygen and hydrogen, and that to form it, the latter is to be combined with half its bulk of the former. From this fact it is easy to calculate the relative weights of the elements in this liquid.

The specific gravity of hydrogen is to that of oxygen as 0.07321* to 1.1088.† Now, $0.07321 : 1.1088 :: 1 : 15$ nearly, but since 2 volumes of hydrogen enter into the composition of this liquid, the ratio in weight is as 1 : 7.5, and 100 parts of water will consist by weight of

Oxygen	-	-	-	-	88.24
Hydrogen	-	-	-	-	11.76
					<hr/>
					100.00

Sir H. Davy considers the hydrogen in water as two proportions, and hence in making that element unity he has doubled the number representing the ratio in weight of oxygen; according to this view water consists of 2 proportions of hydrogen 1, and 1 proportion of oxygen 15. By Mr. Dalton and other chemists, water is inferred to be a compound of 1 proportion, or 1 atom of each of the elements. Hence, the ratio of the hydrogen to the oxygen is as 1 : 7.5 very nearly; for these numbers represent the relative weights of the constituents of this liquid. In Dr. Wollaston's table, the weight of the atom of oxygen being 10, that of the atom of hydrogen is designated by 1.32. Dr. Thomson makes it 1.25. We may then state the composition of water to be as follows.

* M. M. Biot and Arago.

† Mess. Allen and Pepys.

		Prop.			Atoms.			Weight.
Oxygen	-	1	-	-	1	-	-	88.24
Hydrogen	-	1	-	-	1	-	-	11.76
		<hr/>			<hr/>			<hr/>
		2			2			100.00

And its representative number will be $7.5 + 1 = 8.5$.

CCXCIV. Water is an insipid, inodorous, colourless, and transparent liquid, which owes its form, according to the common chemical doctrine, to the specific caloric which it contains. At 32° of Fah. it crystallizes in hexaedral prisms, and under mean barometrical pressure is converted into vapour at 212° . In this form its bulk is increased according to the experiments of Dr. Black about 1800 times. The latent caloric of water is estimated at 140° ; and that of its vapour at 950° . When exposed to the air, this liquid evaporates at all temperatures, the quantity vaporised bearing a certain ratio to the degree of heat, as may be seen in the table of Mr. Dalton upon the force of vapour. (CXIII.) This change takes place even when the water is in the state of ice. On a cold night, Mr. Howard exposed 1000 grains of snow to the air, and in the morning it was found to have lost 60 grains by evaporation. Water is incompressible, or at least nearly so, as was first proved by the celebrated experiment of the Florentine Academicians, in which a hollow sphere of gold, previously filled with water, was submitted to strong pressure. In a short time the liquid was seen to ooze through the pores of the metal, and to collect in small drops upon its surface. M. Dessaignes has shown that a sudden and violent shock or blow upon water, causes it to give out light, and this luminous appearance has been explained upon the assumption of the compressibility of this liquid.*

CCXCV. Water as usually presented to us always contains air. This may be proved by applying heat to the liquid; for long before the temperature rises to 212° , numerous air bubbles will be seen adhering to the sides of the vessel, and as

* Thenard. *Traité de Chimie*, t. i. p. 489.

the heat increases, these bubbles will rise to the surface and disappear. If water be put under a receiver upon the table of an air-pump, and the air be exhausted, the gaseous fluid will collect in bubbles and ascend. From 100 cubic inches of spring water, Dr. Henry obtained 4.76 cubic inches of an elastic fluid, which was a mixture of 3.38 inches of carbonic acid, and 1.38 of atmospheric air. Mr. Dalton in his *New System of Chemical Philosophy* states the proportion somewhat differently, the average quantity of air in 100 cubic inches of water being, according to his experiments, about 2 cubic inches, from 5 to 10 parts consisting of carbonic acid, and the remainder of 38 of oxygen and 62 of azote. Water in fact is capable of absorbing portions of every elastic fluid, but the quantity varies with the nature of the gas. Some of the acid gases are condensed with great rapidity and in very large proportions, while the simple gases, with the exception of chlorine, are absorbed only in small proportion. This appears from the experiments of Dr. Henry and of Theo. De Saussure. Dr. Henry found that 100 parts of water, freed from air by previous boiling, and at the temperature of 60°, absorbed of

Nitrous gas	-	-	-	-	5 parts.
Oxygen	-	-	-	-	3.55
Phosphuretted hydrogen	-	-	-	-	2.14
Gaseous oxide of carbon	-	-	-	-	2.01
Carburetted hydrogen	-	-	-	-	1.40
Nitrogen	-	-	-	-	1.47
Hydrogen	-	-	-	-	1.53

The absorption was promoted by pressure, and he draws the conclusion, "that under equal circumstances of temperature, water takes up, in all cases, the same volume of condensed gas, as of gas under common pressure.* In the experiments of Saussure, 100 volumes of water freed from air condensed of

* *Philos. Trans.* for 1803, p. 276.

Olefiant gas	-	-	-	-	15.3	volumes
Oxygen	-	-	-	-	6.5	
Carbonic oxide	-	-	-	-	6.2	
Carburetted hydrogen	-	-	-	-	5.1	
Hydrogen	-	-	-	-	4.6	
Nitrogen	-	-	-	-	4.1*	

These results differ both from those of Mr. Dalton and Dr. Henry. Water which has thus been impregnated with the gases above mentioned is not changed in its sensible qualities, and when it is exposed to heat, the elastic fluids are evolved unaltered. The power which causes this mixture or combination has not been developed. By the chemists just quoted, the union is considered as merely mechanical, and the analogous property in charcoal has been explained by Saussure upon the same principle. Yet if this were the case, it might be supposed that the volumes of the gases absorbed would be the same in all, which is obviously not the fact.

Water in the act of freezing discharges a quantity of air, which is sometimes retained among the crystals, and gives to the ice a vesicular appearance.

CCXCVI. As water absorbs air, so it has been found that all elastic fluids contain water or vapour. At the temperature of 65° , atmospheric air holds in suspension about $\frac{1}{30}$ of its volume of aqueous vapour. It is of some consequence in a theoretical point of view to ascertain the state in which this water exists, or the relation which it has to the gaseous fluids. From many of them it can be obtained by the action of those bodies which have a strong attraction for water, such as the deliquescent salts, lime, and potash. It appears to be rather mechanically diffused through, than chemically united with the particles of the airs, and hence has been called *hygrometric* water. In one or two instances, this liquid is retained by a strong affinity, drying substances have no effect in withdrawing it from the gas, and it is supposed to be intimately united with its substance. This has been called *combined*

* Annals of Philosophy, vol. vi. p. 340.

water. M. M. Gay-Lussac and Thenard, who have investigated this subject with great precision, conclude from their experiments, that all the gases contain hygrometrical water, excepting those which have a strong attraction for, or are very soluble in this liquid; that it is not found either in fluoboric, or silicated fluoric acid gas; nor probably in ammonia; and that the only gas, in which combined water is present, is muriatic acid.* It is affirmed by M. M. Clement and Desormes, that all gases which are not very soluble in water contain at a given temperature the same proportion of aqueous vapour. Sir Humphry Davy conceives that the gases which have a strong attraction for water contain a gaseous compound of water and the peculiar elastic fluids. M. M. Gay-Lussac and Thenard had shown that when a drop of water was introduced into ammoniacal or muriatic acid gas, the air was absorbed, and the water, instead of disappearing, increased in size. This fact was considered as proving that the gas was not capable of containing hygrometric water. If instead of pure water, a drop of a concentrated solution of ammonia be put into ammoniacal gas, and the temperature be gently raised, it disappears and according to Davy continues invisible so long as the heat is uniform. The phænomena are similar when analogous experiments are made upon muriatic acid and silicated fluoric acid gases. Each of these elastic fluids then may contain a small quantity of a compound of water and the respective gas, and it may be called an hydrated gas.† The affinity existing between water and some of the gases is exceedingly strong. M. M. Gay-Lussac and Thenard ascertained that the fluoboric acid gas became cloudy when exposed to any of the elastic fluids, excepting muriatic acid, and the former was employed by them as an hygrometric substance. It appears from the observations of Sir H. Davy, that some of the gases containing combined water may be made to yield a small quantity to drying sub-

* *Recherches Physico-Chimiques*, t. ii. p. 92.

† *Elements of Chem. Philos.* part i. p. 189.

stances. Thus dry hydrate of potash will slowly attract moisture from ammonia, and dry muriate of lime from sulphurous acid gas. Silicated fluoric acid, and fluoboric gases render sulphurous acid turbid, and the same effect is produced upon fluoric acid gas by fluoboric gas. Dr. Henry found that after muriatic acid had been exposed to hygrometrical substances it did not yield by voltaic electricity so much hydrogen as in its usual state.

CCXCVII. Many solid bodies enter into combination with, and retain water with great obstinacy. Pure potash, even in its driest state, contains nearly 20 per cent. of this fluid, and so powerful is the affinity by which they are united, that it is impossible to separate the whole of the water without decomposing both compounds. Barytes, lime, strontian, &c. absorb a certain proportion of water; and when many of the metallic oxides are separated from their acid combinations, they are precipitated in the form of *hydrates*. From some of these compounds the water may be driven off by a red heat. The strongest acids, such as sulphuric, nitric, and chloric, even when obtained in their most concentrated state, contain water, and no method has been yet discovered of depriving them of this liquid. The energy of the attraction is estimated by the temperature necessary to their vaporisation. M. Gay-Lussac and other distinguished chemists infer that this water is essential to their liquid state, and that the dry acids would probably exist as permanently elastic fluids. Water then is here considered to act the part of a base, and to enter as water into the composition of the liquid acids. A different view of the constitution of this class of bodies has been taken by Sir H. Davy. It is his opinion that oxygen and hydrogen, in the proportions in which they form water, are not passive elements of a combination, but that they unite with bases as oxygen and hydrogen. The acids above mentioned, therefore, upon this hypothesis, instead of being compounds with water, are in fact compounds with oxygen and hydrogen, and it is considered as a just expression of facts to say, that

liquid nitric acid consists of 2 proportions of hydrogen, 1 proportion of azote, and 6 of oxygen ; instead of viewing it as is commonly done, as a compound of 1 proportion of azote and 5 proportions of oxygen united with 1 proportion of water. The composition of chloric acid is considered the same as that of nitric acid, excepting that the former contains 1 proportion of chlorine, and the latter 1 of azote. Hence it would follow that there are very few of the salts which really contain the acids and alkalies from which they are formed.*

If water exist as such in hydrated metallic oxides, and in saline compounds, it must be in the solid state, and it appears from the optical properties of some individuals of the latter class, that in them it is in the form of *ice*.

CCXCVIII. Water is never found in nature in a state of perfect purity. As its solvent power is extensive, it must as it percolates through the ground dissolve variable quantities of earthy and saline matter. From these it may be freed by distillation. When the liquid contains these foreign substances in quantities sufficient to impart to it a perceptible taste, and the power of producing medicinal effects upon the system, it is termed a mineral water. If the compounds of iron predominate, it is called a chalybeate ; when it contains sulphuretted hydrogen, it is sulphureous ; and saline, when the compounds dissolved are of the class of neutral salts. Carbonic acid is a very common ingredient, and the waters of Ballstown and Saratoga, which are probably the strongest of the kind in the world, yield more than an equal volume of this elastic fluid, together with variable proportions of salts with earthy, alkaline, and metallic bases.

Water is the solvent generally employed in chemical operations, and as a whole, or as furnishing oxygen and hydrogen, it must be considered as an active agent in the œconomy of the globe. Wherever water and air can penetrate, changes in the forms or properties of matter are gradually produced ; and some of the effects result from its mechanical operation.

* Journal of Science and the Arts, vol. i. p. 287.

As this liquid passes to the solid state, it expands, according to Mairan about $\frac{1}{4}$ of its volume; and this expansion is exerted with prodigious force, as was proved at Florence upon a sphere of copper, to burst which required a power equal, according to Muschenbroeck, to 27720 pounds; and at Quebec in an extensive suite of experiments by Major Williams. Hence it happens in cold countries, that when the water, which has insinuated itself into the crevices of rocks, becomes congealed, its expansive force is often sufficient to detach large masses. Hence, also, when the soil, which has been frozen to the depth of 20 or 30 inches, is thawed on the return of spring, it is found loosened and better adapted to the purposes of culture.

According to the experiments of Mr. Everard, a cubic foot of distilled water weighs, at the temperature of 55° , 62.5 pounds, or 1000 ounces avoirdupois, within 106 grains troy. If, therefore, its specific gravity be denoted by unity or 1.000, the relative specific gravities of other bodies will indicate the number of ounces contained in a cubic foot. Distilled water, therefore, is always taken as the standard in estimating the specific gravities of liquids and solids. The specific gravity of the elastic fluids is usually referred to that of air, which is equally represented by 1.000.

Until lately water was considered by chemists almost as passive in most chemical operations, but it is now regarded in many instances as an active agent, and as furnishing elements for new combinations, or determining decompositions by which the nature of compounds is altered, or their elements are evolved.

CCXCIX. While hydrogen is burning at the end of a capillary tube, if a thin glass tube from 24 to 30 inches in length, and from $\frac{3}{4}$ to 1 inch in diameter be brought over it, so that the flame shall be within the bore, sounds, more or less acute, will be produced. This fact was discovered by Dr. Higgins. For the success of this experiment it is necessary that the bore of the tube through which the gas issues be very small, and that the velocity of the current be great. This phænom-

enon has been explained by Pictet and De la Rive upon the principle that vibrations are excited in the substance of the tube by the rapid expansion and condensation of the watery vapour near and around the flame, which being communicated to the air occasion a musical sound.*

This subject, however, has been lately examined with care by Mr. Farady, and from the results of his experiments he draws the conclusion that the sound is owing neither to the condensation of aqueous vapour, nor to the rapid passage of the air through the tube, but to the vibration of the flame occasioned by the successive and rapid combustion of explosive gaseous mixtures. That it is not the consequence of the formation and condensation of vapour is proved by the continuance of the sound after the tube is heated above 212° ; and still more satisfactorily by the power of a flame of *carbonic oxide* to produce the same effect, though no water is formed by the combination of its elements with oxygen. Nor has the current of air any influence, because sounds are produced when the flame is inserted in a tube open only at one end, or under a bell-glass, as was observed by Dr. Higgins. All the other inflammable gases, as well as the vapours of ether and alcohol, were caused by peculiar management to produce sounds, varying more or less in tone and intensity. But hydrogen gas is the best, because the temperature excited during its combustion is intense, it combines with a comparatively small volume of oxygen, and the flame is less easily extinguished. Mr. Farady explains this phænomenon upon the principles of Sir H. Davy, that flame results from the combination of explosive mixtures. When the mixture is not extensive, the combustion is continued, and there is no explosion; but if large quantities of explosive mixtures be fired, there results a detonation. When air from a pair of bellows is propelled upon a fire, a mixture of atmospheric oxygen and inflammable gaseous matter is formed, and this mixture coming into contact with flame explodes, these explosions are

* Nicholson's Journal, 8vo series, vol. i. p. 129.

rapid, and produce a roaring noise. The combustion of inflammable gases in a tube is conceived to be perfectly analogous; a current of air is propelled upon the flame, which mingling with the gas, as it issues from the jet, forms explosive mixtures which are successively inflamed, and give rise to sound.*

Compound Blow-pipe.

CCC. From the great condensation which takes place during the combination of oxygen and hydrogen, it occurred to Mr. Robert Hare of Philadelphia, while engaged in a series of experiments with a blow-pipe of new construction, that the heat produced must be proportionally high; and that if the gases were propelled by pressure from separate reservoirs, mingled just before they issued from a tube of small diameter, and inflamed at the extremity, a powerful instrument might be obtained for the production of intense temperatures. Accordingly, having prepared his hydrostatic blow-pipe, he performed with it in 1801—2, a variety of experiments, the results of which were soon after published in Europe.† It was found that by the aid of this blow-pipe, the most refractory substances, such as silex, alumina, and platina, were melted with the greatest facility; even lime and magnesia entered into fusion, though with more difficulty, and barytes was converted into an enamel containing brilliant yellow specks. Platina when held in the flame melted and burned, or evaporated, and iron consumed with a brilliant light.

The hydrostatic blow-pipe having been found rather complicated in construction, Mr. Cloud of the United States mint invented a more simple apparatus, composed of a tin vessel divided in the middle by two partitions, so as to form two distinct reservoirs, one for the oxygen and the other for the hydrogen. By the pressure of water, the gases were pro-

* Journal of Science and the Arts, No. 10.

† Tilloch's Magazine, vol. xiv. p. 230. Annales de Chimie, No. 134.

pelled through separate tubes, mingled just before they left them, and inflamed at a capillary orifice.* With this compound blow-pipe, as it has been called, the effects of an ignited stream of oxygen and hydrogen gases have been frequently witnessed in this country.

In the year 1813, professor Silliman of Yale College published an account of an extensive suite of experiments made with the inflamed gases, the results of which not only confirmed those of Mr. Hare, but also demonstrated in a still more positive manner, the prodigious power of this kind of blow-pipe.†

CCCI. The results of these experiments attracted but little attention in Europe ; and although mentioned by writers and lecturers upon the science, they do not appear to have been repeated until the year 1816. At this period, Dr. Clarke of Cambridge, who was apparently ignorant of what had been done in this way in America for the last fourteen years, conceived the idea of producing intense heats by the ignition of oxygen and hydrogen gases in the proportions necessary to constitute water. Accordingly, he had constructed an instrument upon the plan of Mr. Brooke's blow-pipe,‡ into which was crowded by a condensing syringe a mixture of 1 volume of oxygen, and 2 volumes of hydrogen ; and as the ignition of any considerable stream of the gases would necessarily produce an explosion in the whole, he availed himself for the purpose of obviating this difficulty, of a principle discovered by Sir H. Davy, of the cooling agency of tubes with fine bores. It had been demonstrated by that distinguished chemist, that when a tube with a very fine bore was connected with a reservoir containing an explosive mixture, and the gases were pressed out and inflamed at the point of the jet, the flame would not be communicated through it to the air in the reservoir, because, in taking a retrograde direction, it must come into contact with the sides of the tube, and

* Plate vi. fig. 5, and explanation.

† Memoirs of the Connecticut Academy, vol. i. part iii.

‡ Plate vi. fig. 6, and explanation.

so much heat would be carried off by the conducting power of its substance as to diminish the temperature of the gases below their exploding point. A glass tube, therefore, the bore of which was about $\frac{1}{80}$ of an inch in diameter, was fitted to the stop-cock instead of the usual jet, and with this instrument filled with an highly condensed mixture of hydrogen and oxygen gases in due proportions, and the stream of which was transmitted through the flame of a spirit-lamp, Dr. Clarke executed a series of experiments of a nature almost precisely similar to those of Mr. Silliman, but detailed in a more elaborate manner.* But this blow-pipe is not a safe instrument. Notwithstanding the precautions taken by Dr. Clarke and others, explosions have often occurred, and as they are exceedingly violent, and often rend asunder the instrument, propelling its fragments with great force, its use is dangerous. To prevent these accidents, various methods have been proposed to arrest the retrograde progress of the flame; a cylinder of brass has been fitted into it, which is so formed as to enable it to contain water or oil, and it is further protected by the use of sections of cane with minute pores, or pieces of wire-gauze upon the principle of Sir H. Davy's safety-lamp. Dr. Hope recommends that the cylinder should be stuffed with wire-gauze; and it has been proposed by Dr. Wollaston to transmit the mixed gases through a fagot of glass capillary tubes previously to their issuing from the jet. The proposition has even been made to confine the gases respectively in separate reservoirs; but none of these methods, excepting the last, can be considered as offering a perfect security to the operator, for explosions have taken place even in the best constructed apparatus, and Dr. Clarke has been obliged ultimately to resort to the use of a partition of thick boards, the instrument being placed upon one side, and the experimenter upon the other.

From theoretical considerations it might be supposed that a more intense temperature should be produced in the flame of the English than the American oxy-hydrogen blow-pipe. The

* Journal of Science and the Arts, vol. ii. p. 104.

gases are more uniformly mingled, and the compression which they experience in rushing through a narrow tube under a pressure amounting to several atmospheres, ought upon the principles of Sir H. Davy to exalt the temperature in proportion. But the deductions from theory do not accord with fact. Upon comparing the effects produced by the instruments of professor Silliman and Dr. Clarke, there will be found no decided advantage in favour of Brooke's blow-pipe; and the comparison may be easily made, for it is not a little remarkable that nine-tenths of the experiments of the latter were performed upon substances of the same nature as those which were employed by the former gentleman. The oxy-hydrogen blow-pipe of Dr. Clarke is an elegant instrument, and may be employed with convenience in experiments upon a small scale, but for all the purposes of exhibition, the compound blow-pipe of Mr. Cloud has much the advantage. From what has been observed, it will be seen that the former is merely a modification of the latter, that the object in both is the same, viz. to produce an intense temperature, that their powers are equal, and that the circumstance of the gases being previously mingled in the one, while they are separated in the other, cannot affect the rightful claims of Mr. Hare to the discovery and application of this important fact.

CCCII. Hydrogen combines with chlorine. It was discovered by M. M. Gay-Lussac and Thenard, that if a mixture of equal volumes of the two fluids were exposed to the direct action of the solar rays, an explosion would take place. But if two vessels of the same size be filled one with chlorine and the other with hydrogen in a dry state, and after being connected with each other, be exposed to common day-light, for the experiment will not succeed in the dark, the colour of the chlorine will gradually disappear, and in a short time it will become colourless and transparent.* On examining the contents of the vessel, a peculiar elastic fluid will be found as the result, which differs in properties both from chlorine and hydrogen. This gas is muriatic acid.

* *Rechères*, t. ii. p. 127.

Muriatic acid.

CCCIH. This acid in combination with water was known to the alchymists; but the present mode of obtaining it was discovered by Glauber. It has been successively designated by the names of *spirit of sea salt*, *marine acid*, *muriatic acid*, and *hydrochloric acid*. Dr. Priestley first examined its properties in the elastic form.

Muriatic acid is never obtained for experiment by the direct combination of its elements. The mode usually practised is to put two or three ounces of common salt into a small, but deep-bodied retort, and to pour upon it an equal weight of sulphuric acid. A quantity of bibulous paper is introduced into the neck to absorb the moisture which distils over; after the atmospheric air is pressed out, the mouth of the retort is immersed in quicksilver in the mercurial trough, upon the shelf of which are placed receivers filled with the same fluid, and which may be closed with accuracy. Common salt is a chloride of sodium; when the acid comes in contact, the water which it contains is decomposed, its oxygen is transferred to the sodium, and its hydrogen to the chlorine, the results are soda and muriatic acid, the last of which passes in the state of gas into the receiver. When the spontaneous action of the materials has ceased, it may be renewed by the application of a gentle heat.

CCCIV. The acid thus obtained is a permanently elastic, colourless, and transparent fluid. Its taste is exceedingly acid, and when applied for any length of time to the skin, it acts upon it like a caustic. It is pungent and suffocating, and when breathed pure by small animals, occasions instant death. When mixed with atmospheric air and inhaled, it produces cough and difficulty of respiration, but when thus diluted it does not act upon the lungs with the same energy as chlorine. As 1 volume of hydrogen combines with 1 of chlorine to form this gas, and as there is no condensation, the specific gravity of muriatic acid must be the mean between

those of its elements, or 1.271, compared with atmospheric air as unity; and 100 cubic inches will weigh 38.76 grains. It is incapable of supporting combustion. When a lighted candle is introduced into the gas, it is extinguished, but before the flame expires it assumes a tint of green, and the same colour will be observed when the wick is again lighted.

Muriatic acid has a powerful affinity for water. When diffused in the air it forms a white cloud, and the same effect takes place when mingled with any of the airs, excepting the fluoboric gas; it proceeds from its combination with their aqueous vapour, and the formation of a hydrate.

If a vessel filled with this air be opened under the surface of cold water, an immediate condensation takes place, a vacuum is formed, and the pressure of the atmosphere forces the liquid into the vessel with prodigious rapidity. The same effect is produced, although more slowly, when a few drops of water are conveyed into a long eudiometric tube filled with the gas and standing over mercury. Ice exhibits the same phænomenon, and is itself immediately melted. The quantity of gas, which water at the ordinary temperature of the air is capable of condensing, is astonishingly great. The lowest estimate is that of Sir H. Davy, in which the proportions in volume are stated to be as 480 to 1; forming a solution of muriatic acid, the specific gravity of which is 1.2109.* It is this aqueous solution which is commonly known by the name of muriatic acid. During the absorption the temperature rises. The quantity absorbed depends upon the temperature of the water, the proportion of the gas constantly diminishing as the heat approaches the boiling point. When the solution is heated to 212° , the acid passes over in the form of gas, and it was in this way that Dr. Priestley first obtained it in the elastic form. Various tables have been constructed by Mr. Kirwan, Mr. Dalton, and Mr. E. Davy, for the purpose of showing the quantity of real acid in this liquid at different degrees of density. The following table exhibits the results of Dr. Ure's

* Elements, Part 1. p. 253.

experiments ; pure liquid muriatic acid of the specific gravity of 1.192 at 60° Fah. which contains 28.3 per cent. of dry acid, being mixed with different quantities of water.

Acid Grains.	Water. Grains.	Proportions.		Spec. grav. at 60°.	Temp. on Mixture.	Dry acid per cent.
1080	+	120	= 90 + 10	1.1730	80°	25.47
960		240	80 20	1.1536	82°	22.64
840		360	70 30	1.1844	85°	19.81
720		480	60 40	1 1150	90°	16.98
600		600	50 50	1.0960	88°	14.15
480		720	40 60	1.0765	83°	11.32
360		840	30 70	1.0574	79°	8.49
240		960	20 80	1.0384	75°	5.76
120		1080	10 90	1.0192	69°	2.83

There are two remarkable circumstances attending these experiments ; first, the evolution of heat from the mixture of two liquids which are not saline, without any condensation of their volume ; a fact which is opposed to the doctrine that caloric results only from increase of density ; and the second, that we have a true chemical compound without any change of density, a fact which has before been stated with regard to the formation of muriatic acid gas by the mixture of 1 volume each of chlorine and hydrogen, the resulting compound occupying the space of 2 volumes.*

In obtaining pure muriatic acid for experimental purposes, distilled water is usually saturated with the gas in the complicated apparatus of Woulf.

CCCV. As commonly procured it is a liquid of a straw yellow colour, extremely acid to the taste, capable of reddening blue vegetable colours, and of emitting white fumes on exposure to the atmosphere. The cause of its colour is not known, but it may be rendered nearly colourless by repeated distillation and absorption by pure water. It is not often obtained of a higher specific gravity than 1.170, in which state

* Annals of Philosophy, vol. x, p. 272.

it will be seen by the above table, that it contains about 25 per cent. of dry acid. It is the opinion of Sir H. Davy, that hydrate of this acid exists in muriatic acid gas, and that the elements of the compound are in the state of mutual saturation.

The liquid acid is decomposed by heat; and also by sulphuric acid, which, when dropped into it, occasions a violent effervescence, and the production of a copious vapour. These fumes result from the union of the acid gas with the aqueous vapour of the atmosphere.

It does not act apparently upon the supporters of combustion.

It is decomposed by many of the combustible bases, particularly the metals, and compounds are formed of chlorine and those bodies, which were formerly called muriates. Most of these are *chlorides*, and some of them have the property of decomposing water, by which they are converted into real muriates or compounds of muriatic acid and oxides.

As muriatic acid results from the direct mixture of equal volumes of hydrogen and chlorine, it is obviously to be considered as a compound of 1 proportion of each, and its representative number will be $1 + 33.5$ or 44.5 ; the specific gravities of the gases being in the ratio of 1 to 33.5, the weights of the elements may be easily obtained, and 100 parts of the acid will consist of 2.89 parts of hydrogen and 97.11 of chlorine.

CCCVI. In its liquid form, this acid is an important instrument to the chemist. It is employed in many analytical researches, either as a whole, or as furnishing elements for other compounds. It is used in the arts, and occasionally in the practice of medicine. M. Guyton ascertained that it possessed the power in common with chlorine of neutralizing the properties of putrid miasmata, and both have been strongly recommended by him as substances very effectual in fumigating infected apartments, and in removing the cause or diminishing the effects of impure air. The process with regard to muriatic acid is very simple, consisting merely in pouring an

equal weight of sulphuric acid upon common salt, in a convenient vessel, and placing it in the room, which is to be closed. After some hours it is opened and ventilated. By adding powder of black oxide of manganese to the salt in the proportion of 2 parts of the former to 5 of the latter, and using sulphuric acid, chlorine will be evolved, and the disengagement of this element, as well as of muriatic acid in the preceding process, will be facilitated by the application of a gentle heat.

CCCVII. The nature of muriatic acid has for several years constituted a very interesting subject of research, and within a short time the different views of its composition have been so intimately connected with the most important doctrines of the science, that it has occupied a great deal of the attention of the most distinguished chemists.

It has been already stated that by Mr. Scheele the discoverer of chlorine, muriatic acid was considered as a compound of that substance and phlogiston, and that when distilled with black oxide of manganese, the hydrogen was transferred to the metal, and the dephlogisticated marine air or chlorine was disengaged. As the theory of Lavoisier prevailed, M. Berthollet succeeded in giving a more simple and apparently satisfactory explanation of this action. He inferred that chlorine was produced by the direct union of oxygen from the manganese with the muriatic acid employed; that muriatic acid therefore was an elementary body, and oxygenized or oxy-muriatic acid a compound of this simple substance with oxygen; that when a combustible body, such for example as phosphorus, was brought into contact with it, the gas was decomposed, and its oxygen was transferred with so much rapidity as to cause the phænomena of active combustion, and that the products of this action were in this instance muriatic and phosphoric acids; if the metals were employed they became oxidized, and then combined with the muriatic acid to form dry muriates; that it was capable of combining with the salifiable bases, and of forming peculiar salts which were called oxy-muriates; that it changed vegetable colours by the

transfer of its oxygen to the colouring matter ; that it might be analyzed by exposing its aqueous solution to light, oxygen being disengaged and simple muriatic acid remaining in solution ; and finally, that by this method, and from the quantity of muriate of silver formed by dropping nitrate of silver into this liquid, it might be proved to consist of 89 parts of muriatic acid and 11 of oxygen.

CCCVIII. The experiments and reasonings upon which was founded the opinion of the simple nature of muriatic acid, and the constitution of oxy-muriatic acid, appeared to be so conclusive, that no doubt was entertained of its truth until after the researches of the distinguished French chemists, M. M. Gay-Lussac and Thenard in 1809. They found that the dry muriates were incapable of being decomposed by heat, or when mixed with substances which exerted strong affinities for their bases, and exposed to an high temperature ; that muriatic acid gas could not be procured in a dry state, but that when evolved from its combinations, water must be present, and that this water was essential to its gaseous constitution. They further concluded that it contained 0.25 per cent. of water.*

These experiments were repeated and others were performed at a subsequent period which confirmed their previous observations. Fused boracic acid, when heated with dry muriate of silver, produced no change, and no muriatic acid was disengaged, but so soon as the mixture at the same temperature was brought into contact with the vapour of water, a large quantity of the acid gas was formed. Dry and pure charcoal did not decompose the same salt, but muriatic acid in the elastic state was disengaged when water was present. The same circumstance of the necessity of the presence of water to produce muriatic acid was shown in an experiment in which oxy-muriatic gas was transmitted over dry charcoal, at first a small portion of muriatic acid was formed, but as the temperature was increased, and new

* *Memoirs d'Arcueil*, t. ii. p. 357.

portions of the gas were applied, it became less, and after a time the oxy-muriatic gas passed over unaltered, so that this elastic fluid was not decomposed by dry charcoal. In order to ascertain the quantity of oxygen contained in oxy-muriatic gas they brought it into contact with ammonia, both were decomposed, and a quantity of azote equal to one third of the volume of the chlorine was disengaged. Now ammonia is formed of 1 volume of azote united with 3 volumes of hydrogen; hence the oxy-muriatic gas absorbed from the ammonia a quantity of hydrogen equal to its own volume, and as 2 volumes of hydrogen combine with 1 volume of oxygen, they concluded that oxygenated muriatic acid contained half its volume of oxygen. They therefore succeeded in an experiment which had been before imperfectly performed by Cruickshanks, of decomposing this gas by mixing it with its own volume of hydrogen in close vessels, and exposing the mixture to indirect light; the yellow colour of the oxy-muriatic gas gradually disappeared, and the elastic fluid remaining was muriatic acid. When the mixture was kept in the dark, no effect was produced, and when exposed to the direct impression of the solar rays, a violent explosion took place. Now it was supposed that in this experiment, the oxy-muriatic gas was decomposed, the hydrogen combining with its oxygen and forming water, and that this water existed in, and was essential to the gaseous constitution of muriatic acid. From experiments similar in principle to those just detailed, these chemists inferred that water was necessary to the existence of muriatic acid in the elastic form, and that oxy-muriatic acid could not be decomposed, excepting by those bodies which contain hydrogen.* But they remark that since the oxy-muriatic acid is not decomposed by charcoal, it may be supposed from this fact, and from those which have been detailed, that this gas is a simple body, and the phænomena which it presents may be explained well enough upon this hypothesis; but that they should not support the opinion because

* *Recherches Physico-chimiques*; t. ii. p. 93—180.

these facts appear to them to admit of a better explanation upon the idea that oxy-muriatic acid is a compound body.

That water was present in muriatic acid had been inferred from the time of Priestley ; it had been shown by Dr. Henry, that it existed in the proportion of about 1.4 grain in 100 cubic inches of the acid gas, and Sir Humphry Davy in his earlier researches into this subject concluded, from the action of potassium upon muriatic acid, that it contained from $\frac{1}{8}$ to $\frac{1}{10}$ its weight of water.

CCCIX. But in the year 1810, the original hypothesis of Scheele was revived by Sir H. Davy, and illustrated and supported by experiments with all the ingenuity for which he is so remarkable. The fact that charcoal, even when heated to whiteness, produces no effect upon oxy-muriatic gas first led him to doubt whether that elastic fluid contained oxygen, and his first series of experiments upon the action of oxy-muriatic acid with tin, ammonia, and phosphorus, and in mixing ammonia with the sulphuretted and phosphuretted muriatic compounds, satisfied him that no substance known to contain oxygen could be procured from oxy-muriatic acid by this mode of operation. He found also that when 15 or 16 parts of this gas were added to from 40 to 45 parts of ammonia, an immediate condensation of nearly the whole took place, from 5 to 6 parts of azote were evolved, and dry muriate of ammonia was the result. No water, he affirmed, was produced in this experiment. On reverting to the experiment of Cruickshanks, and of M. M. Gay-Lussac and Thenard, in which muriatic acid resulted from the mixture of equal volumes of oxy-muriatic gas and hydrogen, he found that when these gases were mingled in the above proportions, and detonated over mercury, there was always a slight deposition of vapour. He inferred that the muriatic acid produced resulted from the direct combination of the hydrogen with the oxy-muriatic acid, and hence was led to doubt the existence of combined water in muriatic acid gas. As M. M. Gay-Lussac and Thenard had proved that in the usual cases in which

oxygen had been obtained from oxy-muriatic gas, water was present, and as muriatic acid results from the combination of the former with hydrogen, it is scarcely possible, he observes, to avoid the conclusion, that the oxygen is derived from the decomposition of the water, and consequently, that the idea of the existence of water in muriatic acid gas is hypothetical, depending upon an assumption which has not been proved, the existence of oxygen in oxy-muriatic acid gas.* When this gas is mixed with a certain volume of hydrogen, it forms muriatic acid, and if the latter be made to act upon mercury or other metals, hydrogen is evolved, and an oxy-muriate, similar to that which is produced by the combustion of the metal in oxy-muriatic gas, is produced.

The action of water upon these dry muriates, as they have been considered, but which are properly compounds of oxy-muriatic acid with inflammable bases, may be easily explained upon these principles; for when added in certain proportions to Libavius' liquor, for example, or the oxy-muriate of tin, it is decomposed, the oxygen combines with the tin, and the hydrogen with the oxy-muriatic acid, and the muriatic acid thus formed then unites with the oxide of tin, and the two constitute a muriate, which appears in the state of a solid crystalline mass, from which oxide of tin and muriate of ammonia may be obtained by the addition of ammonia. From all these facts, and a multitude of others of the same character, Sir H. Davy draws the conclusions, that as yet we have no right to say that the oxy-muriatic acid has been decomposed; and as its tendency to combination is with inflammable matters, it may belong to the same class of bodies as oxygen; that it combines directly with them to form simple binary compounds, which are analogous in properties to the oxides; that when brought into contact with the oxides, it either produces the expulsion of their oxygen, or causes it to enter into new combinations; that like oxygen it must be combined in large quantity with inflammable matter to form

* Phil. Trans. for 1810.

acid bodies ; that it unites directly with hydrogen to form muriatic acid, and hence hydrogen may be considered as the base, and oxy-muriatic gas as the acidifying principle in this body ; that it expels oxygen from some of the inflammable bases, and is expelled by that element from others ; that it has no acid properties, and acts upon vegetable colours through the medium of the water which is present, and which is decomposed ; and finally, that like oxygen, it is to be considered as a supporter of combustion.

CCCX. It was not to be supposed that a theory which was opposed to doctrines universally received and established, and which if adopted must have the effect to subvert or at least to modify the principles of the science itself, should be implicitly received without any previous examination into its merits. Accordingly not long after the opinions of Sir H. Davy were published, there appeared in *Nicholson's Philosophical Journal*,* a series of papers by Dr. Murray of Edinburgh, in which the principles of the new theory were controverted and experiments were detailed, the results of which were thought to be subversive of that doctrine.

It has been said that the phænomena observed in the action of oxy-muriatic gas or chlorine upon other bodies may be explained equally as well upon the old as upon the new theory ; that with regard to the experiment in which muriatic acid is formed by the mixture of equal volumes of chlorine and hydrogen, the effect may be to cause a combination between the hydrogen and the oxygen of the oxy-muriatic gas, by which water will be formed, and that this combines with and is essential to the constitution of gaseous muriatic acid ; and that the dry muriates are incapable of being decomposed by inflammable bodies in a dry state, because there is no water present to favour the transition of the muriatic acid from a solid to an elastic form. The arguments against the theory that chlorine or oxy-muriatic gas is a simple body may be reduced to two, viz. 1. that there are facts explained

* Vols. xxviii. xxix. and xxx.

by the former doctrine which cannot be accounted for upon the hypothesis of Sir H. Davy. 2. that the hydrogen which appears when muriatic acid is made to act upon inflammable bodies, proceeds not from the decomposition of the acid itself, but of the water previously combined with the acid. With regard to the first the want of action between chlorine and dry charcoal is a striking example. If chlorine be a simple body and analogous in properties to oxygen, it is urged by Dr. Murray as a very singular fact, that no action should take place between them, considering the strong affinities exercised by charcoal and its tendency to unite with oxygen. No reason for this inertness can be assigned by those who embrace the new theory, it must at present be considered as an ultimate fact; but it is easily explained upon the old doctrine. In the decomposition of oxy-muriatic acid, the muriatic acid must either become insulated, in which case a certain portion of water is necessary to its constitution, or it remains in combination with the oxidated product of the decomposing substance. Hydrogen effects the decomposition in the former mode and the metals in the latter, but it can be produced by charcoal in neither, for it cannot afford any water, and its oxidated product, whether carbonic oxide or carbonic acid, exerts no affinity for muriatic acid; it is the only substance therefore exerting an attraction for oxygen which is incapable of decomposing oxy-muriatic acid.*

CCCXI. In order to establish the doctrine of Berthollet, it may be proved either that oxy-muriatic acid contains oxygen, or that muriatic acid contains *combined* water. In order to demonstrate the first of these propositions, Dr. Murray mixed over mercury two volumes of carbonic oxide,† and two and a half of oxy-muriatic acid, previously dried by exposure to muriate of lime and allowed to remain at rest 24 hours, no carbonic acid was formed and the gases were unchanged; the experiment was repeated with the addition of a little water,

* Supplement to Murray's System of Chemistry, p. 102.

† A gas formed by the union of 1 proportion of charcoal and 1 of oxygen.

and in the same space of time the gases were found to be carbonic and muriatic acids. But as it might be thought that the production of these substances was owing to the decomposition of the water, its oxygen combining with the carbonic oxide to form the carbonic acid, and the hydrogen with the chlorine to produce muriatic acid, the experiment was repeated with the variation of employing only the basis of water or hydrogen. A mixture of hydrogen, carbonic oxide, and oxy-muriatic acid in a dry state was made and exposed to light, and after 24 hours, the gases were found to consist of muriatic and carbonic acids. The conclusion then from this experiment was unavoidable, that the carbonic oxide combined with one portion of the oxygen contained in the oxy-muriatic acid and formed carbonic acid, while the hydrogen united with another portion and produced the water, which was essential to the gaseous state of the muriatic acid. But this production of carbonic acid was denied both by Sir H. Davy* and by Dr. John Davy,† and the latter attributed the appearance of this gas in Dr. Murray's experiments to the presence of water or atmospheric air. The former in using ammonia to condense the results of this experiment could find no trace of carbonic acid, and the carbonic oxide remained unchanged. The experiment was again performed by Dr. Murray, ammonia was employed, the carbonic oxide disappeared, and the salt formed effervesced with a diluted acid, and the solution precipitated muriate of barytes.‡ In pursuing the investigations of the mutual action of oxy-muriatic acid, hydrogen, and carbonic oxide, Dr. J. Davy was induced to try the effect of light upon a mixture of oxy-muriatic gas and carbonic oxide, and he found that in the course of two or three minutes they combined with each other and formed a peculiar compound,§ the properties of which he afterwards examined, and to which he gave from its mode of formation the name of

* Phil. Trans. for 1811.

† Nicholson's Journal, vol. xxviii. p. 193.

‡ Ibid, vol. xxix. p. 191.

§ Ibid, vol. xxx. p. 28.

Phosgene gas. It was this gas, he asserted, which was produced in the experiments of Dr. Murray, which united with ammonia, and which formed carbonic acid by the action of a diluted acid. The existence of this gas has been since sufficiently demonstrated.

These experiments then were instituted to ascertain the presence of oxygen in oxy-muriatic or chlorine gas.

CCCXII. The other mode of proof is that relating to the presence of water in muriatic acid. According to Sir H. Davy's hypothesis this gas is the real acid, free from water, and it is admitted that if it contain water that hypothesis is precluded and the common opinion is established; for all the facts whence the existence of hydrogen as an element of muriatic acid is inferred, would necessarily fall to be explained from the agency of this water, and in the synthetic experiment of the production of muriatic acid gas by the mutual action of hydrogen and oxy-muriatic acid, it must be held that the latter contains oxygen, which combining with the hydrogen, forms the water held in solution by the muriatic acid.*

The common proofs of the existence of water in muriatic acid by the hydrogen given off during its action upon the metals is ambiguous, because the production of the gas may be accounted for upon either theory, and the same objection may be urged against the formation of water when muriatic acid is brought into contact with the metallic oxides. In order therefore to ascertain with precision that the water obtained in the combinations of muriatic acid proceeds from the gas itself, a substance must be employed which contains no oxygen, and which is condensed as it combines with the acid. Ammonia appeared to Dr. Murray to answer these purposes. Muriatic acid and ammonia in a dry state were combined over mercury and the solid salt, when collected and heated near to its point of volatilization in a small retort, produced a notable quantity of water, amounting to about $\frac{1}{6}$ the weight of the acid. But it having been objected that the water ob-

* Murray's Supplement, p. 107.

tained might have been absorbed from the atmosphere, the salt was formed from the dry gases in a retort and exposed to heat, without having been in contact with the atmosphere, and water was equally evident. This experiment was also performed by Dr. Traill and Dr. Bostock with the same results; and it was successfully repeated before Sir H. Davy himself and others, by Dr. Hope in the College laboratory at Edinburgh.

CCCXIII. In 1815 Professor Berzelius of Sweden published a paper upon this subject, entitled, *A comparison of the old and new Theories respecting the nature of oxy-muriatic acid*, in which he attempted to show that the new doctrines were incompatible with the theory of definite proportions, while the principles of this theory might be applied with success to the compounds of muriatic and oxy-muriatic acids in adopting the opinions of Berthollet.* But in the outset the Swedish chemist has involved himself in hypothesis in asserting that muriatic acid is a compound of 1 volume of a base and 2 volumes of oxygen, an opinion opposed in fact to the old doctrine, which considers that acid as simple or still undecomposed.

CCCXIV. Notwithstanding the objections which had been urged by Dr. Murray against the theory of Sir H. Davy, it continued to gain ground, and the probability in its favour was much increased by the discovery of iodine. This substance existing in the solid form presented a body more favourable to examination than chlorine; its properties have therefore been faithfully studied, and in proportion as they became developed the analogy between them and those of chlorine was found proportionally greater, and the doctrine which was applied to the one was equally applicable to the other. They both form acids with oxygen and hydrogen, they form analogous compounds with inflammable bases, they are both attracted in the voltaic circuit to the positive pole

* Annals of Philosophy, vii. p. 272, translated from the German Annalen de Physik, for Sept. 1815.

of the battery and both support combustion ; if one be compounded therefore the other cannot be simple, but iodine has never been decomposed, and its high specific gravity and the weights of it which enter into combination, seem to connect it with some of the metallic bases.

CCCXV. The subject of the nature of chlorine has been very lately resumed and much interest has been excited by the recent experiments of Dr. Ure of Glasgow, Dr. Murray, and Sir Humphry Davy. The first of these chemists sublimed muriate of ammonia through silver, copper, and iron contained in tubes of green glass, and heated to the temperature of ignition out of contact with the air, and obtained water, while hydrogen gas was evolved and the metals were converted into muriates ; but no traces of water could be perceived when dry charcoal or quartz was substituted for the metals ; and he concluded from his experiments, that gaseous muriatic acid was a compound of 1 volume of dry acid and 1 of vapour of water. But as he employed common sal ammoniac instead of the salt formed by the direct combination of its elements, and as the experiment was thus liable to the objection that water might have previously existed in it, Dr. Murray undertook to perform it in a more unexceptionable manner, and to cause a more complete abstraction of the water by conducting it in an apparatus similar in principle to the Cryophorus of Dr. Wollaston. In a retort of the capacity of 7 cubic inches, fitted with a stop-cock, and exhausted, 60 cubic inches of ammoniacal gas were combined with the requisite quantity of muriatic acid gas, each having been carefully dried, the former by exposure to potash, the latter to muriate of lime. The stop-cock was then detached from the retort, the excess of ammoniacal gas was drawn out and replaced by atmospheric air, the salt was pushed down from the neck ; and it was connected with another similar retort, the joining of the two being secured by cement. Part of the air in the last was driven out by exposure to heat, in that state it was closed and immersed in a mixture of muriate of lime and ice ; the

body of the other retort was placed in oil, the temperature of which was gradually raised to the 420° of Fah. Moisture condensed upon the upper part of the neck when the heat had risen to 220° , and continued for some time to increase; it then diminished, from the continued application of the heat carrying it forward into the cold retort, and at the end of the experiment a considerable part of the body of the last was encrusted with a thin film of ice.* It occurred to Dr. Murray that the experiment might be performed by another method, which consisted in transmitting muriatic acid over the metals exposed to a high temperature. About 100 grains of iron filings, clean and dry, were strewed in a glass tube 2 feet in length, which was afterwards inserted in an iron case and laid across a furnace, one end of it dipped under the surface of mercury, while to the other was connected a second tube containing fused muriate of lime, and to this was further connected a retort affording muriatic acid gas. When the iron was raised to a red heat, and the gas was slowly transmitted through the first glass tube, elastic fluid escaped from the opposite end, and though no moisture appeared in the anterior part of the tube, it immediately condensed in the part which was cold, beyond the iron filings. This accumulated in globules and at length ran into a small mass in the bottom, the sides were bedewed for a length of 6 inches, and a thin film of moisture appeared beyond, nearly its whole length. In a subsequent experiment, the apparatus being the same, muriatic acid, which had been exposed for several days to the action of muriate of lime, was transmitted over iron filings heated to redness, the quantity of gas was about 55 cubic inches, and the production of water was as evident in this as in the preceding experiment. From the results of other experiments conducted upon the same principle, Dr. Murray draws the conclusion that the water thus obtained must have been derived from the muriatic acid gas and have existed in

* Experiments on Muriatic acid gas &c. from the Transactions of the Royal Society of Edinburgh, 1818.

it in a state of *combination*, for after exposure to substances powerfully attractive of aqueous vapour, it could not have been diffused in it in the form of *hygrometric* water. But he remarks that there is a considerable difficulty attending the theory of the experiment. The quantity of water obtained was greater than was to be looked for, on the doctrine of muriatic acid containing combined water, for it must be held that in the action of metals on muriatic acid gas, the metal attracts oxygen from the water, the corresponding hydrogen is evolved, and the oxide formed combines with the real acid. No water therefore ought to be deposited, for none is abstracted from the acid, but that which is employed in the oxidizement of the metal. This will be apparent by attending to the proportions, in a single example, from the scale of chemical equivalents; 100 grains of iron combine with 29 of oxygen, and this oxide unites with 99 of real muriatic acid. This quantity of acid exists in 131.8 of muriatic acid gas, combined with 32.8 of water; and this portion of water contains 29 of oxygen with 3.8 of hydrogen. There is present therefore exactly the quantity of oxygen which the metal requires to combine with the acid.—How then is the production of water to be accounted for? It may be explained, Dr. Murray thinks, upon one of two suppositions, either that the metal may require less oxygen than has been supposed to convert it into an oxide, or that the oxide attracts more real acid, so as to liberate a larger quantity of water. The former supposition is considered as improbable, but the latter may be supported by analogies drawn from other saline compounds, many of them containing a large proportion of acid, and existing as super-salts. It is reasonable to suppose therefore, that a super-muriate was formed in these cases; and it was found that solid muriate of zinc, which deliquesced and became liquid by exposure to the air, afforded a solution sensibly acid.

In the second part of the paper alluded to above, Dr. Murray enters minutely into the consideration of chemical theo-

ry; after stating the analogies which exist between the undecomposed substances, he proceeds to the subjects of acidity and alkalinity, and proposes a theory of the constitution of muriatic acid and chlorine, "as perhaps more probable, or at least, as on the whole, according better with the present state of chemical theory," than either of the doctrines which he had previously discussed. We shall state these views more at large in a future chapter, and shall merely remark here, that he thinks all the weak acids may be mere binary compounds of bases with oxygen or with hydrogen, but that the strong acids may be considered as ternary compounds of bases with oxygen and hydrogen; that chlorine therefore may be regarded as a radical united with oxygen; and muriatic acid as this radical, combined with oxygen and hydrogen. This view of the constitution of these substances, which has very strong analogies in its favour, he thinks will do away some anomalies which muriatic and oxy-muriatic acids have always presented.

CCCXVI. The experiments of Dr. Ure which were thought to demonstrate the presence of water in muriatic acid gas have been repeated by Sir Humphry Davy, and from them he has drawn a very different conclusion. By attending to circumstances which were overlooked by that chemist, he has destroyed the confidence which might have been placed in their results. He has found that the water produced by the decomposition of muriate of ammonia by the metals, and the transmission of muriatic acid over their surfaces, is owing to the combination of the hydrogen with the oxygen of the oxide of lead, and of the silex contained in the glass, that in proportion as this source of fallacy was obviated, the quantity was less, and when completely removed that the production of water ceased.

Such is a general outline of the two theories of the nature of chlorine or oxy-muriatic gas and muriatic acid. The circumstances that muriatic acid is formed by the mixture of chlorine and hydrogen; that oxygen cannot in any case be ob-

tained from oxy-muriatic gas, unless water be present ; that muriatic acid during its combinations with many bodies gives off hydrogen ; that when some of the compounds of chlorine are brought into contact with water, there are strong grounds for believing that the liquid is decomposed, and the results are muriatic acid and combinations of the bases with oxygen ; that chlorine is not affected by pure and dry charcoal heated even to whiteness ; that when electrified in the voltaic circuit it is attracted to the positive pole ; and that it suffers no change when transmitted over surfaces intensely ignited, lead me to adopt the opinions, that it is a simple substance, or at least that it has never been decomposed, and that muriatic acid is a compound of chlorine and hydrogen.

The existence of dry muriatic acid, as conceived by Dr. Murray and professor Berzelius, is hypothetical, and it seems not a little singular, that while these distinguished chemists believe that water acts the part of a base to the strong acids, and prevents them from assuming the elastic form, the same liquid should be considered essential to the gaseous constitution of muriatic acid. “The weight of chlorine, its absorbability by water, and the analogy of some of its combinations to bodies known to contain oxygen, are arguments in favour of its being a compound ; and it is possible that oxygen may be one of its elements ;” but at present, “it must be regarded according to the just logic of chemistry as an elementary substance.”*

The doctrine of the simple nature of chlorine is also strengthened by its analogy to iodine, and by the discovery of a class of bodies which have been called *Hydracids*, and which consist of bases united with hydrogen, such as hydro-sulphurous, (*sulphuretted hydrogen*,) hydrocyanic, and hydriodic acids. And lastly, it may be stated that M. Berthollet himself has given up the theory of oxy-muriatic gas being a compound of muriatic acid with oxygen, and become a convert to the new opinions upon this subject.

* Davy.

Hydriodic acid.

CCCXVII. Hydrogen and iodine do not act upon each other at common temperatures, but it was ascertained by M. Clement that when iodine was put into a tube containing hydrogen, and heated, they combined and formed an acid. This compound, which will be described by the name of Hydriodic acid, may be obtained, as was found both by Gay-Lussac and Davy, by the action of iodide of phosphorus upon water, or of phosphorus upon moistened iodine. Four parts of iodine and one of phosphorus are mixed together, moistened with water and put into a small retort or glass tube connected with a mercurial apparatus. When heat is applied, the liquid is decomposed, the oxygen is transferred to the phosphorus, and the hydrogen to the iodine, hydriodic acid is formed, which passes in the state of gas into the receiver.

It is an elastic fluid, colourless and transparent, of a very acid taste, and having an odour similar to that of muriatic acid. Its specific gravity is 4.443; but as it consists of 1 volume each of hydrogen and vapour of iodine, it should be the mean, provided there be no condensation, between 0.0732 and 8.6195 or 4.3463. It is composed of 1 proportion of hydrogen 1, and 1 of vapour of iodine 117.7, and it is represented by 118.7.

When chlorine is brought into contact with hydriodic gas, a decomposition takes place, muriatic acid is formed, and the vessel is instantly filled with the beautiful violet coloured vapour of iodine.

This gas is partly decomposed at a red heat, and the decomposition is complete if it be mixed with oxygen, water is formed and iodine separated.

Hydriodic gas is very soluble in water, it renders that liquid dense, and when combined with it in considerable quantity, gives to it the property of smoking in contact with the air. The liquid acid is prepared with facility by putting

iodine into water, and transmitting through it a stream of sulphuretted hydrogen, a decomposition of the gas takes place, its sulphur is separated, while its hydrogen unites with the iodine and forms hydriodic acid. The liquid is afterwards filtered. It is colourless and transparent, and, like sulphuric acid, may be concentrated by evaporation. It boils at the temperature of $262\frac{1}{2}^{\circ}$, and its specific gravity is then 1.7. This property of hydriodic acid, says M. Gay-Lussac, to boil at so high a temperature, renders it a powerful acid, and prevents it from being disengaged from its combinations by the volatile acids.

It is decomposed by many of the strong acids, and iodine is either precipitated, or exhaled in purple vapours. Chlorine is the most delicate test to detect the presence of hydriodic acid, iodine being separated; but the chlorine must be cautiously added, otherwise the iodine will be redissolved.

In the state of gas, it is decomposed by mercury, iodide of that metal is formed, and hydrogen equal to half the volume of the gas remains. When the liquid is poured into solutions of the metallic salts, it forms beautiful precipitates, differing in colour according to the nature of the metal. The composition of these precipitates is similar to the analogous compounds of chlorine, i. e. they are iodides.*

CCCXVIII. Pure hydrogen gas is rarely, if ever found in nature, but it is evolved in abundance during the spontaneous decompositions to which vegetable bodies are exposed, and is then combined with carbon. In this form it exists in coal mines, and from its inflammability often occasions destructive explosions. It is copiously produced, also, in combination with sulphur, and occasionally dissolved in spring water, to which it imparts a nauseous taste and odour. Sulphur springs, as they are here termed, are common in the United States. Hydrogen gas from its extreme levity is now generally employed for filling balloons. It was used for this purpose in 1783, by M. Charles, a French philosopher, and in his first

* Gay-Lussac. On Iodine ;—Annals of Philosophy, vol v. p. 102.

experiment he ascended to the height of 10500 feet above the surface of the earth.*

The ponderable basis of this gas has never been obtained in a separate state, nor been proved to consist of more than one element. In fact, its extreme levity, and the small quantities by weight in which it enters into combination, are considered by Sir H. Davy as arguments against the probability of its ever being resolved into other forms of matter. In its relations to other bodies it is opposed to oxygen.

From some anomalous circumstances connected with hydrogen, some speculation has been occasioned respecting the nature of its base. When a globule of mercury is negatively electrified by a strong voltaic battery, while in contact with water, it was found by Stromeyer that no hydrogen was disengaged, that the metal became elongated, and had the appearance of an amalgam. The experiments of Mess. Hisinger and Berzelius have likewise shown that mercury, negatively electrified in contact with sal ammoniac, increases in bulk, and is apparently converted into an amalgam. Now as it appears to be a property characteristic only of the metals to amalgamate with quicksilver, it has been too hastily concluded by some, that the basis of hydrogen or of nitrogen is metallic in its nature. These facts undoubtedly furnish materials for much curious speculation, but the conclusions which have been drawn from them cannot be supported without additional evidence.

* Mr. Brande's History of Chemistry.

SECTION II.

Azote or Nitrogen.

CCCXIX. When the oxygen contained in atmospheric air has been withdrawn by bodies introduced into it, and for which it has an affinity, the residue is azote. The most expeditious mode of obtaining this result is to pass into a receiver nearly filled with common air, and standing over water, small portions at a time of the gas called nitric oxide, red fumes will be produced, which on coming into contact with the water will be absorbed, and the liquid will rise proportionally in the vessel. The addition of the gas is to be continued until it cease to produce the coloured vapour. Nitrogen may also be procured by distilling the animal fibre with diluted nitric acid in a retort connected with the hydro-pneumatic apparatus. This gas was discovered in 1772 by Dr. Rutherford of Edinburgh, and in 1776 by Mr. Scheele of Sweden. It was at first called *mephitic* or *non-respirable air*, a name which was changed by Lavoisier to *azote*, from α *privative*, and $\zeta\omega\eta$ *life*; Chaptal bestowed upon it the appellation of *nitrogen*, because it is the radical of nitric and nitrous acids, &c. The last term is preferable, but the first is in common use.

CCCXX. Azote is a permanently elastic, invisible, and insipid fluid, rather lighter than atmospheric air, its specific gravity being 0.9691,* and 100 cubic inches at the temperature of 60°, and under mean barometrical pressure, weighing 29.73 grains. Its specific gravity compared with that of hydrogen is at 13 to 1. Its representative number is 13. According to the experiments of Berard and De la Roche, its capacity for caloric in an equal bulk is the same as that of atmospheric air; in equal weights, as 1.0318 to 1.0000.

This gas is incapable of supporting combustion or respiration. A lighted candle plunged into it, or even lighted phos-

* M. M. Biot and Arago.

phorus is extinguished, and small animals are suffocated. It exerts, however, no positively injurious action upon the lungs, and it is fatal to life only by excluding oxygen. Water takes up but a very small quantity of azote, 100 cubic inches absorbing, according to Dr. Henry, only 1.47 inches at 60°, and according to Theo. De Saussure, 4.01 cubic inches.

The properties of this element in its gaseous state are entirely negative. It produces no effect upon lime-water,* nor upon vegetable colours, and it has neither taste nor odour. Azotic gas exists in great abundance in nature, for it constitutes nearly $\frac{4}{5}$ of the atmosphere. Its base enters into the composition of organized bodies, particularly those of an animal nature; and combined with oxygen, it forms a constituent part of the important salt, called nitre, which is found native in considerable quantities.

Atmospheric air.

CCCXXI. The air is considered by chemists as composed essentially of oxygen, azote, carbonic acid, and aqueous vapour. Taken collectively, it must be received as a mixture of the substances above mentioned, with all those bodies which on exposure may be converted into vapour, or which are sufficiently attenuated to allow of their suspension.

It is a transparent, invisible, inodorous, elastic fluid, surrounding the globe, and rising to the height of about 46 miles from its surface. It is indefinitely expansible by heat. Its specific gravity, when the barometer stands at 30, and the thermometer at 60°, is considered as unity or 1.000. It has been adopted as the standard to which the relative weights of other gases are referred. An hundred cubic inches weigh, according to the experiments of Sir George Shuckburgh, 30.5 grains, troy weight.

* When the gas is obtained from flesh, and diluted nitric acid, it will at first render lime water turbid, for during the reaction of the materials, it appears that a portion of carbonic acid is formed. It may be removed by allowing the air to remain for some time in contact with water, or more effectually by washing it with lime water.

The knowledge which we now possess of the properties of the air has been gradually unfolded. Its gravity was known to Galileo, and demonstrated in a satisfactory manner by Torricelli. It was shown by Paschal, that the density decreased as the distance from the surface of the earth increased, and it has since been determined that the density diminishes in geometrical progression, while the height augments in an arithmetical progression. The weight of the air is measured by the barometer, and in its ordinary state it is able to support a column of mercury 30 inches in height. The length of the column then is affected by the pressure, and Saussure found at the top of Mont Blanc, the pinnacle of the Alps, that the mercury stood only at 16 inches and one line; nearly half the pressure of the atmosphere, therefore, was taken off by ascending between 15000 and 16000 feet from the surface. The air in these high regions is proportionally rarefied, and the effects produced upon the body as described by Saussure, Col. Beaufoy, Humbolt, and others, are exceedingly unpleasant, particularly when the person is in motion.

CCCXXII. A phænomenon, which has been mentioned in strong terms by all those who have ascended to great heights, is the very deep blue colour verging on black, of the sky. The air is transparent, but on looking into space from the surface of the earth, it always presents a tint more or less deep of azure. This blue colour is attributed by Saussure to the reflection of the blue rays of light by the vapours contained in the atmosphere. In order to ascertain its intensity, he painted a band of paper with 16 different shades of blue, from the deepest, which appeared almost black, and which was marked No. 1, to the lightest, marked No. 16. On comparing these shades with the colour of the sky at different heights, it was found that at Geneva on a certain day, the colour corresponded with the seventh shade of his *cyanometer*, as it was named, at Chamouni it was between the fifth and sixth, and at the summit of Mont Blanc between the first and

second.* When the number of shades of blue on the cyanometer was increased to 51, the last being the deepest, the colour of the sky at Geneva corresponded with 22.5 ; at Chamouni, 347 toises above that place, with 18.9 ; and at the summit of the Col du Géant, with 31.† Upon the summit of Mont Blanc, the sky was equal to the 39th division of the cyanometer. The spectacle of the sun, or moon and stars, moving through an atmosphere almost black, is described as producing, from its novelty and from the circumstances in which the observer is placed, very singular feelings.

The invention of the air-pump by Otto Guericke, and its improvement by Boyle, furnished the means of completing the demonstration of the effects of the gravity and elasticity of the air. Its dilatability was measured by Mariotte, and its relations to light and sound were pointed out by Hooke, Newton, Boyle, and Derham. The electrical phenomena of the atmosphere were investigated by Franklin, and more lately by Forster. The state in which water exists in it has been made the subject of experiment by De Luc, Saussure, Le Roy, and Dalton ; and Howard has presented us with the natural history and a nomenclature of clouds.

CCCXXIII. The fact that atmospheric air is not a homogeneous fluid was not discovered until the year 1774. Before this period its compound nature seems to have been partially known to Mayow, Hooke and Rey, but Dr. Priestley laid the foundation of the knowledge of its composition by his discovery of oxygen gas ; Scheele appears to have been the first who submitted it to analysis, and its nature was nearly at the same time demonstrated in a series of decisive experiments by Lavoisier.

Mr. Scheele put about four ounces of the liquid called hydro-sulphuret of potash into a vessel of the capacity of about 24 ounces, sealed its mouth, inverted it in water, and allowed it to remain in that state about three weeks. When opened under the surface of water, a portion of the liquid rushed in

* Voyages dans les Alpes, t. iv. p. 197. † Ibid, p. 290.

and occupied about 4 ounces of the 24, which had been exposed to the action of the hydro-sulphuret. To the air which remained, and which was lighter than an equal bulk of atmospheric air, and incapable of supporting respiration or combustion, he gave the name of foul air, and concluded that the atmosphere was composed of two elastic fluids, and that it might be formed by a mixture of 2 parts of foul air with 1 of empyreal air or oxygen gas.

Four ounces of fine quicksilver were introduced by Lavoisier into a matrass, the neck of which was bent in such a manner as to be connected with a mercurial apparatus. The body of the vessel was then exposed for twelve days to a degree of heat little short of the boiling point of the metal. On the first day no change was perceptible, but on the second, small red particles began to appear upon the surface of the quicksilver, the number and size of which continued to increase until the twelfth day, when, perceiving no further action, the fire was extinguished. At the commencement of the experiment, the bulk of the air in the vessel amounted to about 50 cubic inches, and at the conclusion it was equal only to between 42 and 43 cubic inches, and it had therefore lost about $\frac{1}{6}$ its bulk. This air was incapable of supporting respiration or combustion. The red particles when collected weighed 45 grains; they were put into a small retort, connected with a proper apparatus and exposed to heat. When nearly red hot they began to decrease in bulk, and in a few minutes disappeared, $41\frac{1}{2}$ grains of running mercury remained in the retort, and 7 or 8 cubic inches of an elastic fluid were collected in the receiver. This gas supported combustion in an eminent degree, and exhibited all the characters of oxygen.* It is obvious that if the air had been mixed with the residual air in the vessel, the bulk would have been the same as before the experiment, and as the former supported respiration and combustion in a greater degree than atmospheric air, while the latter was incapable of doing either, the gaseous fluid in the

* Elements of Chemistry, vol. i. p. 64. Am. ed.

vessel must have been decomposed, one portion of it combining with the mercury, and the other remaining in its pure and simple state. Subsequent experiments of the same kind completely established the fact, that the atmosphere is composed principally of the two elastic fluids, oxygen and azote.

CCCXXIV. If well burnt quick-lime be exposed for some time to the air, it gradually falls down into a powder, which, instead of exhibiting the active properties of pure lime, is comparatively inert and insipid. When pure potash or soda is exposed in the same way, it soon becomes liquid and mild. Lime water in the same circumstances acquires a white pelticle upon its surface, which continues to increase in weight until it overcomes the resistance of the water, it then sinks and is soon succeeded by another pellicle. This process goes on until the whole of lime collects at the bottom in the form of an insoluble precipitate. Now if these substances be submitted to examination, they will be found to effervesce with acids, and to give off an elastic fluid, which is carbonic acid. This elastic fluid then must have previously existed in the atmosphere; in fact it forms a constituent part; for the experiments succeed at all times, in all places, and at all distances from the surface of the earth which have yet been reached.

If, instead of the substances above mentioned, we substitute oil of vitriol, or the deliquescent salts, the acid will gradually increase in bulk and appear proportionally diluted; while the salts become moist and finally liquid. In warm weather a body colder than the atmosphere, will, when exposed to it, have its surface covered with dew, which gradually collects into drops and runs down its sides.

These facts prove that water exists in the air and the most probable opinion upon the subject is, that this compound is contained in it in the form of vapour. Atmospheric air then consists essentially of oxygen, azote, carbonic acid, and aqueous vapour.

CCCXXV. As soon as the general nature of this compound elastic fluid was ascertained, chemists directed their attention towards the proportions of its constituent parts. Many different methods of analysing the air have been proposed and practised, yet such is the subtile nature of the subjects upon which they have operated, or such are the imperfect modes which have been adopted for this purpose, that the relative proportions of the constituents have never been ascertained with perfect precision. The art of analyzing the air has been termed *Eudiometry*. As the affinities of oxygen for other bodies are not only more extensive, but also more energetic than those of nitrogen, the principle upon which all the eudiometric processes are founded is to abstract the former, and to decide upon its proportion by the diminution in volume sustained by the air submitted to experiment. The bodies usually employed for this purpose are the hydro-sulphurets of lime and potash, nitric oxide gas, phosphorus and hydrogen gas. As the properties of none of these bodies, excepting hydrogen, have been described, we shall not enter here minutely into the modes by which the analysis is completed. They will be mentioned under their respective heads. Of all the numerous processes of eudiometry that by hydrogen is probably the least liable to error, as the proportions in which this gas combines with oxygen are well known, the condensation may be considered as complete, and the operation is conducted with no other difficulty than the use of an electrical machine.

The use of hydrogen as an eudiometric substance was proposed by Volta, and the method consisted in mixing known proportions of the gas with the atmospheric air, firing the mixture by the electric spark, and ascertaining the purity of the air by the consequent diminution of volume. The fact may now be considered as established, that 100 volumes of oxygen require for their saturation 200 volumes of hydrogen, and therefore in the analysis of atmospheric air, to 100 measures of this fluid should be added 50 measures of hydrogen, and the mixture when exploded by electricity will be

found to diminish one third of its volume, which indicates the amount of the oxygen present. When the mixture is in the above proportions the condensation is equal to 63 in volume, and this number divided by 3 gives 21, the proportion of oxygen in 100 of atmospheric air. This process may be conducted in the eudiometric tube, standing over water or mercury, and it is necessary to add rather more hydrogen than may be required for the saturation of the oxygen contained in the air which is to be analysed. This method has been recommended by M. M. Gay-Lussac and Humbolt as the most correct and elegant of all the processes of eudiometry.

From the results of experiments made by different chemists and by different methods, it appears that the mean of their numbers is about 21 parts of oxygen in 100 of the air. But it also contains azote, carbonic acid, and aqueous vapour. The proportion of the acid gas is always the same, but the amount of the water is variable. As an approximation however to the truth, the constituents of the air may be stated as follows.*

Nitrogen gas	-	77.5	by measure,	-	76.55	by weight.
Oxygen gas	-	21.	-	-	23.32	
Aqueous vapour		1.42	-	-	1.03	
Carbonic acid	-	0.08	-	-	0.10	
		<hr/>		<hr/>		
		100.00		100.00		

The statement of Dr. Thomson† does not differ essentially from that of Dr. Murray. It gives

98.9
air
1.0
vapour
0.1
carbonic acid
<hr/>
100.0

* Murray's Elements of Chemistry, vol. i. p. 265. 3d ed.

† System of Chemistry, vol. iii. p. 191.

From calculation a different estimate has been given by Dr. Prout. According to him the air is a chemical compound, and is composed of 4 volumes of azote and 1 of oxygen; hence if the atom of oxygen be considered as 10, and that of azote as 17.5, then it will be found to consist of 1 atom of the former and 2 atoms of the latter; or per cent. of 22.22 of oxygen and 77.78 of azote.*

CCCXXVI. Such are the bodies which may be demonstrated to be present in atmospheric air, by eudiometric processes; but it is certain that other matter often exists, which, although sufficiently proved by its effects, cannot be detected by the most rigid chemical examination. The processes of eudiometry are rude and imperfect, and we are yet ignorant of the chemical properties of those invisible and attenuated substances which often float in the atmosphere, and produce the most positive effects on the human system. M. M. Lavoisier and Guyton Morveau analyzed a portion of air from one of the wards of the *Saltpetrière* at Paris, which had been closely shut for six hours, and the impression of which was so unpleasant as to cause Lavoisier to faint, without finding any thing in it which was not common to the purest air.

It has been found that the relative proportions of the elements of the air are uniformly the same in all quarters of the globe, at all heights from its surface, and in all varieties of climates, being unaffected by the accidental circumstances of health and disease. Different portions of air, analyzed by different chemists, by Sanssure Jun. from the Alps, by De Marti from Spain, by Berthollet from France and Egypt, by Davy from England and the coast of Guinea, by Humbolt from the Peak of Teneriffe and near the summit of the Andes, and by Gay-Lussac and Thenard from the height of nearly 22000 feet, all afforded within a few fractions the same proportions of oxygen and azote. This is one of the most curious circumstances connected with the chemical history of the atmosphere, and the cause of this uniformity of composition has

* Annals of Philosophy, vol. vi. p. 221.

given rise to much ingenious inquiry and curious speculation. There must be some cause operating to counteract the tendency of these gases to separate from each other, from their difference in specific gravity; and it appears to have been until lately almost uniformly the opinion of chemists, that they are mingled by a species of loose affinity, which M. Berthollet indicates by the term *dissolution*; the gaseous state, in consequence of which their particles or atoms are separated to considerable distances, preventing the intimate chemical combination which would necessarily be followed by change of properties.

Mr. Dalton on the contrary maintains that atmospheric air is a mechanical mixture of its elements; that although the particles of a gas are mutually repellent, yet that they neither attract nor repel the particles of other gases, and consequently, that one elastic fluid is in relation to another, like a vacuum. When, therefore, oxygen is mixed with azote, its own particles, being repulsive of each other, recede, and meeting with no other resistance from those of the azote than a slight mechanical obstruction, they will be uniformly diffused among them. The particles of aqueous vapour and of carbonic acid, are in the same way mingled, and the uniformity in the proportions of the constituents of the atmosphere is thus preserved.* This hypothesis is characterized by much simplicity and ingenuity.

When the gases are mingled, the volume of the mixture is the same as that of the airs separately taken; no condensation therefore ensues; neither is the change of properties greater than might be supposed to result from mere mixture. The union of oxygen and nitrogen, known to be chemical, terminates in the production of compounds, some of which still preserve the elastic form, but which exhibit characters very different from those of the atmosphere. From these facts, and others which it is not necessary to mention, I am

* Dalton's Chemical philosophy.

Murray's System of Chemistry, vol. ii. p. 48, and note E.

induced to believe that this heterogeneous fluid is rather a mechanical mixture of its constituent gases, than a product of loose chemical combination, as maintained by M. Berthollet and Dr. Murray, or a true chemical union, as stated by Dr. Prout.

Although oxygen and nitrogen are associated with each other in the atmosphere, yet, as has just been stated, if any combination take place between them, it is feeble, and incapable of materially affecting their properties. But there are modes of bringing them into intimate union, and of forming compounds, each of which is characterized by peculiar properties and relations. These compounds are very important, particularly in a theoretical point of view, and great labour has been employed in investigating their properties and the proportions of their constituents by Sir Humphry Davy, Mr. Dalton, and M. Gay-Lussac. Yet, notwithstanding the repeated researches of these eminent chemists into this subject, a degree of uncertainty still exists relative to the number of the compounds these elements are capable of furnishing, as well as the proportions in those which seemed to be well defined.

There appear to be four compounds of azote with oxygen, which are well characterized, and they will be described by the names of, 1. Nitrous oxide. 2. Nitric oxide. 3. Nitrous acid gas. 4. Nitric acid.

1. *Nitrous Oxide.*

CCCXXVII. Nitrous oxide received its name from Sir H. Davy. It was discovered by Dr. Priestley, who called it Dephlogisticated nitrous air, and the Dutch chemists gave to it the appellation of Gaseous oxide of Azote. Various methods have been pointed out for its production by indirect means, for it cannot be formed by the direct action of its elements. It is now always procured by the distillation of a salt called Nitrate of ammonia, which is crystallized either in the form of prismatic needles, or in the form of a compact

white mass. Both varieties yield, on exposure to heat, nitrous oxide, but for this effect they require different temperatures. Between 275° and 300° , the compact slowly sublimes without decomposition; at 320° it becomes liquid, part sublimes, and part is decomposed; between 340° and 480° it is decomposed with rapidity. The fibrous is not decomposed below 400° , and the actions which produce nitrous oxide cease at 600° . Above this point the decomposition goes on with great rapidity, the nature of the products is altered, and if the temperature be raised to 700° or 800° , a luminous appearance takes place in the retort, followed almost immediately by an explosion.* When the gas is to be obtained for the purpose of respiring it, much time will be saved by employing the compact nitrate.

To procure nitrous oxide then, a quantity of the salt is put into a tubulated retort, and the temperature is to be quickly raised by means of Argand's lamp to about the 450° Fah. The gas passes over whitish and opaque in consequence of a portion of the salt being sublimed. This vapour, together with a small portion of acid which is often disengaged, may be withdrawn by allowing the air to remain for an hour or two in contact with water.

CCCXXVIII. Nitrous oxide is a permanently elastic, invisible fluid, possessing a faint, but peculiar odour, and a distinctly sweetish taste. Its specific gravity, atmospheric air being 1.000, is 1.614, and 100 cubic inches weigh 50.1 grains.

It is capable of supporting combustion. A candle, phosphorus, sulphur, and iron, when previously ignited and plunged into it, burn with nearly the same brilliancy as in pure oxygen. But the temperature to which these bodies require to be previously raised in order that the combustion shall be continued, is higher than is necessary when immersed in oxygen.

Nitrous oxide is absorbed by water, and according to the experiments of Theo. De Saussure, 100 volumes of this liquid take up 76 volumes of the gas. The solution acquires a

* Davy's Researches, p. 85.

sweetish taste, but the presence of the gas does not sensibly alter the other properties of water. The gas is again extricated at the temperature of 212° . It is not altered by exposure to a red heat; but by the action of electricity it is converted, according to Sir H. Davy, into nitrous acid and a gas analogous to atmospheric air.*

Nitrous oxide is decomposable at the heat of ignition by hydrogen, in a variety of proportions. When the quantity of hydrogen very little exceeds that of the gas, water is formed and nitrogen evolved; when the hydrogen is less, water, nitrous acid, oxygen, and nitrogen are generated in different proportions.†

It is not altered by chlorine, nor iodine.

Nitrous oxide was supposed by Sir H. Davy to act the part of an acid in particular circumstances, to combine with the alkalies and form peculiar salts, which he designated by the name of *Nitroxis*.‡ But by Dr. Thomson they are considered as *Nitrites*.§

CCCXXIX. This gas can for a time support respiration, and in demonstrating this fact, Sir Humphry Davy discovered the most remarkable and curious property of the nitrous oxide, the power of highly stimulating without producing a corresponding debility in the animal body. The air may be respired from and into a bladder, an oiled silk bag, or a gazometer, and the lungs must be previously exhausted of atmospheric air. When first inspired, it occasions a sense of fulness about the head, and a slight degree of uneasiness across the breast; as the respiration is continued, the face becomes turgid and sublivid, a thrilling is perceived over the whole body, the impressions upon the organs of sense become more acute, the objects of vision are magnified, and slight sounds are distinctly heard; the brain then becomes affected, delirium more or less takes place, and although the person is often conscious of his situation, an irresistible

* Researches, p. 286.

† System of Chemistry, vol. ii. p. 7.

‡ Researches, p. 290.

§ Ibid, 275.

propensity to muscular exertion is indulged in, and evinced by leaping, dancing, &c. Trains of novel ideas pass rapidly across the mind, but the impressions which they leave are feeble and indistinct. These effects continue from two to four minutes and then subside, often so suddenly that the consciousness returns like that of a person just awakened from sleep. No exhaustion of consequence follows this excessive excitement. The quantity of the gas required to produce these effects varies from 2 to 8 or 10 quarts; and the degree as well as the kind of excitement is modified by the temperament of the person by whom it is inhaled. Its action upon the system is obviously different from that of oxygen, and it does not appear to perform the same function. The blood does not undergo the same change as when oxygen or atmospheric air is breathed, for the countenances of those who are under its influence become livid, and often strike the beholder with terror, while the persons themselves experience the most exquisite feelings of delight. Animals when immersed in this gas are soon killed, the arterial blood has the deep purple colour of that of the veins, and the irritability of the fibre is said to be destroyed. It acts upon the human system as a powerful but fugitive stimulant, and its operation appears analogous to that of ardent spirits, but differing from it in the rapidity with which the excitement is produced, the shortness of its duration, and the freedom from subsequent exhaustion. Persons who are least affected by wine or ardent spirits are those who are acted upon with the greatest difficulty by nitrous oxide. This gas should not be taken by those who are predisposed to pulmonary complaints.

From the experiments of Sir Humphry Davy and of M. Gay-Lussac, it appears that nitrous oxide is a compound of 2 volumes of azote and 1 of oxygen. It will therefore consist of

	Prop.	Atoms.	Weight.
Azote	1	1	63.41
Oxygen	1	1	36.59
	<hr/> 2	<hr/> 2	<hr/> 100.00

It may be represented by $13 + 7.5$ or 20.5 .

2. Nitric Oxide.

CCCXXX. This gas, the Nitrous air of Dr. Priestley, by whom it was discovered in 1772, the Deutoxide of azote of Dr. Thomson, and Nitric oxide of Dr. Murray, is formed indirectly by the action of inflammable bodies upon nitric acid. The most convenient substances to produce this partial decomposition are the metals which do not act upon water, and of these, the preference is given to copper and mercury. A quantity of either of these bodies is put into a tubulated retort connected with the hydro-pneumatic apparatus, an equal weight of nitric acid diluted with 5 or 6 times its bulk of water is added, and a gentle heat is applied. The acid is partly decomposed, it yields oxygen to the metal, the remainder with a smaller proportion of oxygen is converted into an elastic fluid which passes over into the receiver.

Nitric oxide is a transparent and colourless gas, the taste and odour of which have not been well ascertained, because when exposed to the air, it combines with its oxygen, and forms a compound which is distinctly acid. Its specific gravity, compared with atmospheric air, is 1.050; and with that of hydrogen as 14 to 1; 100 cubic inches weigh 32 grains.*

CCCXXXI. It is decomposed in certain circumstances by inflammable bodies. When a lighted taper, or burning sulphur is introduced into nitric oxide, it is immediately extinguished, and phosphorus may be melted and even sublimed in it without alteration. But if previous to its introduction it be in full combustion, this action is not only continued, but it burns

* Davy's Elements, p. 259.

with as much brilliancy as in oxygen gas. Pyrophorus and potassium spontaneously inflame in it; charcoal previously ignited consumes with a feeble light; and it communicates to hydrogen the property of affording a green-coloured flame, when kindled in contact with the air. In all these cases, the gas is decomposed by the inflammable body, which combines with a part or the whole of its oxygen, and disengages nitrous oxide, nitrogen, or a fluid analogous to atmospheric air.

This gas is fatal to animal life. Warm blooded animals when immersed in it are immediately suffocated, and the irritability of the fibre is destroyed. It produces the same effect upon insects, and is equally noxious to growing vegetables. Sir H. Davy attempted to inspire it; in passing through the mouth and fauces it tasted astringent and highly disagreeable; it occasioned a sense of burning in the throat, and produced a spasm of the epiglottis so painful as to oblige him to desist from his attempts to inspire it. Upon opening the mouth to breathe atmospheric air, æriform nitrous acid was immediately formed in it, which burned the tongue and palate, injured the teeth, and produced an inflammation of the mucous membrane, which lasted some hours.* Had the attempt to inspire it succeeded, it is probable that this great chemist would have fallen a victim to his rash experiment.

Water when freed from air by boiling absorbs about $\frac{1}{26}$ of its volume of nitric oxide, which produces in it no obvious change of properties.

This gas exhibits none of the properties of acids.

Chlorine when water is present converts it into nitrous acid, the water being decomposed, its hydrogen combining with the chlorine to form muriatic acid, and its oxygen with the nitric oxide. A portion of its oxygen is abstracted, and it is changed to nitrous oxide, according to Priestley, by iron filings moistened with water; and according to Davy by the alkaline sulphites. The same effect is produced by sulphuretted hydrogen, the hydro-sulphurets, and muriate of tin.

* Researches Chemical and Philosophical, p. 476.

CCCXXXII. The most characteristic property of nitric oxide is its strong attraction for oxygen gas. When caught over water it is colourless and transparent, but on coming into contact with the air, it immediately combines with its oxygen, and forms dense fumes of a reddish yellow colour. The effect is more positive when pure oxygen gas is employed. If the experiment be made over water, this vapour is almost immediately absorbed, the liquid rises in the vessel, and the remaining air, if there be any, becomes again colourless and invisible. If the water contain dissolved the blue colouring matter of vegetables, such as litmus, the solution as it rises changes to a bright red.

It was this property of nitric oxide which suggested to Dr. Priestley its use in the analysis of atmospheric air. As it produces no change in azote, it is obvious that when cautiously added to a portion of air standing over water, it will combine with its oxygen, and form red vapours which will soon be absorbed. Supposing, therefore, that the gas be pure and be not added in excess, it will indicate, by the diminution it occasions in volume, the amount of oxygen in a given bulk of the air exposed to trial. This mode appeared at first sufficiently accurate and of easy execution. But it was afterwards found that the results were varied according to the manner of performing the experiment; and the circumstances which require to be attended to, were pointed out by Mr. Cavendish and Mr. Dalton. It appears that nitric oxide gas is capable of combining with 2, and M. Gay-Lussac affirms with 3 proportions of oxygen. These proportions are determined by the manner in which the gases are mixed, by the form of the tube, by agitating the water or leaving it at rest, &c. According to Mr. Dalton, 21 measures of oxygen gas unite either with 36, or with 72 measures of nitric oxide, and both compounds are soluble in water. The compound produced is determined by the form of the tube; if it be large, and if the water over which it stands be agitated, the gases when mixed come extensively into contact and combine, so as to contain

the largest proportion of oxygen ; but if the tube be narrow, nitrous instead of nitric acid will produced, and this of the two contains the smallest proportion of oxygen. The last mode is preferred by this chemist ; 100 parts of atmospheric air are introduced into a narrow graduated tube standing over water, and 36 parts of nitric oxide are then added, the vapour which is formed is allowed to be absorbed without agitation. When this absorption has taken place, the reduction in volume in the air is noted, and the amount being multiplied by $\frac{7}{19}$ gives the proportion of oxygen in 100 of the air. By M. Gay-Lussac, the method which occasions the largest absorption of oxygen is stated to be the most accurate and uniform. This mode of analyzing the air can hardly be depended upon, for chemists are not yet agreed upon the precise proportions in which these two bodies combine, and circumstances, which occur during the experiment, may have the effect to vary the combinations, and expose the result to uncertainty.

It was in fact the discordance of opinion upon this point which led Sir H. Davy to a more simple method of analysing the air by nitric oxide. Although water alone absorbs but small quantities of this gas, yet if it be conveyed into a solution of the green sulphate or muriate of iron, it is rapidly condensed to the amount of ten times the volume of the liquid. The dark coloured solution thus formed is capable of attracting oxygen rapidly from the air, and if a small glass tube, properly graduated and containing the air to be examined, be brought in contact with it, an immediate absorption takes place, and the process is concluded in a few minutes.

Nitric oxide is applied by the chemist to no other use, than that of analysing the air.

CCCXXXIII. This gas when mixed with oxygen, and exposed to the action of electricity, does not explode. It was ascertained by Sir H. Davy, that when metallic arsenic was sublimed in it, a decomposition took place, the metal combined with 1 volume of oxygen, and there remained 1 volume of azote. Now as half a volume represents the proportion of this element in nitrous oxide, this gas will consist of

		Prop.			Atoms.			Weight.
Azote	-	1	-	-	1	-	-	46.42
Oxygen	-	2	-	-	2	-	-	53.58
		<hr/>			<hr/>			<hr/>
		3			3			100.00.

It may be represented by 13 + 15, or 28.

3. Nitrous Acid Gas.

CCCXXXIV. The deep orange coloured vapour which is produced when nitric oxide comes into contact with oxygen differs both in properties and in the proportion of its elements from those we have already described. It is difficult, however, to examine this compound, as it is absorbed by water and acted upon by mercury. But when 2 volumes of nitric oxide are mixed with 1 of oxygen, both free from moisture, and contained in a vessel previously exhausted of air, they become condensed into about half their volume, and form the nitrous acid gas.

It is an elastic fluid of a deep orange colour, having an acid taste and a disagreeable odour. It reddens vegetable blues, and when applied to animal substances renders them yellow. Its specific gravity compared with that of hydrogen is as 28 to 1, and 100 cubic inches at mean temperature and pressure weigh 65.3 grains. It is rapidly absorbed by water, to which it imparts a tint of green.

In this gas a lighted taper consumes with considerable brilliancy, and ignited phosphorus gives out a vivid light. Charcoal previously inflamed burns in it with a dull red light; but the flame of sulphur is extinguished. Iron wire heated to whiteness is rapidly cooled when immersed in it; the gas is slowly decomposed by tin, copper, and mercury.

When nitrous acid gas is passed into alkaline solutions, a portion of nitric oxide is always evolved; and when one in volume of oxygen is added to two of nitric oxide, and dry

azote is introduced to mark the condensation, no change takes place on the mixture of the gas with fresh portions of dry nitrous gas.*

From the fact that this gas results from the union of 2 volumes of nitric oxide with 1 of oxygen, it will follow that it is composed of 1 proportion of azote, and 4 proportions of oxygen. It will therefore be represented by $13 + 50$, or 43.

4. *Nitric acid.*

CCCXXXV. This is the most important of all the compounds of oxygen and azote, and in it the elements appear to exist in a state of mutual saturation. It was one of the few valuable discoveries of the Alchemists. It has been successively known by the names of Aqua-fortis, Spirit of Nitre, and Nitric acid, the last of which was given to it by the French chemists.

For a demonstration of the composition of this acid, chemists are indebted to Mr. Cavendish. The electric spark was transmitted for several weeks through a mixture of 5 parts of oxygen and 3 of atmospheric air; or of 7 of oxygen with 3 of azote contained in a tube, into which had been introduced a small quantity of a solution of pure potash; a total condensation took place of these elements, and when the alkaline solution was examined, it was found to contain a certain quantity of nitre. This salt is a compound of potash and nitric acid, but as there had previously existed in the solution no trace of the acid, the conclusion was unavoidable, that it was formed by the union of the two gases. Its composition has since been determined by analysis. By the action of inflammable substances it is partially decomposed, the combustible receiving oxygen, and the remainder being converted into one of the gases, the properties of which have been already described.

* Dary's Elements of Chemical Philosophy, part i. p. 263.

When its vapour is transmitted over the ignited surfaces of porcelain, it is entirely decomposed, and converted into azote and oxygen. It is therefore one of the chemical compounds, the nature of which has been most clearly established.

CCCXXXVI. For the purposes of the arts in which it is used in large quantities, nitric acid is obtained from nitre, the salt-petre of commerce. Two parts by weight of this salt in coarse powder are put into a tubulated retort, connected with one or more globular receivers, and 1 part of sulphuric acid is poured upon it. The joinings are rather loosely luted, and the body of the vessel is exposed to heat in a sand bath, the temperature of which is to be gradually raised as high as the 500° of Fah.; the salt is thus decomposed, the acid is disengaged, rises in vapour and flows in drops into the receiver. During this operation, the apparatus becomes filled with the dense reddish fumes of the nitrous acid gas, which, being in part absorbed by the liquid acid, give to it a yellowish colour. It may be freed from the vapour by exposure to heat, and it then becomes colourless and transparent. As the nitre of commerce generally contains a small portion of common salt, a portion of chlorine is evolved during the action of the materials; but it may be removed by dropping into the acid a solution of nitrate of silver, until it no longer occasions a cloudiness; chloride of silver forms, and it is precipitated and the acid may be obtained from it by decantation; a portion of sulphuric acid also is apt to rise with the vapour of the nitric acid, and this may be withdrawn by adding to the liquid solution of nitrate of barytes.

Nitric acid is a transparent and colourless liquid, the specific gravity of which varies from 1.52 to 1.62. It has a peculiar and somewhat disagreeable odour, and it emits white fumes on exposure to the air. It possesses the properties of acids in an eminent degree. Its taste even when very largely diluted with water is acid; it changes vegetable blues to a red colour. In its concentrated state, its activity is such, that when applied to the skin, it produces a stain of a yellow colour, and if the application be continued even erodes it.

CCCXXXVII. In its strongest state it contains water, and no method has yet been discovered of depriving it of this liquid and obtaining it in a dry form. This water amounts, according to Sir H. Davy, to between 14 and 15 per cent. ;* when the acid is of the specific gravity of 1.5, 100 grains of it contain, according to Wollaston, 25.11 of this liquid.† Water appears to be essential to the liquid form of nitric acid, and it has been supposed by M. Gay-Lussac and Professor Berzelius to act towards it the part of a base, giving fixity, if the expression may be allowed, to the acid. Pure nitric acid may be considered as a gaseous body, the specific gravity of which, compared with that of the air, is 2.440 ; 100 cubic inches weigh at 60°, and barometer at 30°, 75.21 grains.‡

Liquid nitric acid is miscible in all proportions with water, and when the mixture is first made, the temperature always rises. When poured on ice or snow a rapid liquefaction takes place, and in consequence of the change of form, a great reduction of temperature is produced. Four parts of concentrated acid added to 7 of dry snow sink the thermometer to -30° ; and 3 parts of diluted acid with 2 of snow reduce the temperature from 0 to -46° . If the materials be previously cooled by exposure to a strong freezing mixture, the cold will be still more intense. It appears from Mr. Cavendish's experiments, that the cooling effect of the acid is the greatest when it is at the two extremes of dilution and concentration. At intermediate degrees of strength, the reduction of temperature is much less. Great cold also results from adding nitric acid to some of the neutral salts in their crystallized state.

This acid when exposed to the air attracts its aqueous vapour and augments in volume.

When exposed to heat, it boils at the temperature of 248° , and is decomposed at a strong red heat into nitric oxide and oxygen gases. According to Mr. Cavendish, it freezes at

* Elements, p. 264.

† Table of Equivalents.

‡ Henry's Elements of Chemistry, vol. i. p. 364, 7th ed.

about -40° ; but M. M. Fourcroy and Vauquelin place its congealing point as low as -66° .

When acted upon by solar light, it is partially decomposed, nitric oxide is disengaged, which imparts to it a yellowish colour.

CCCXXXVIII. From the large quantity of oxygen which enters into its composition, and the loose affinity by which the higher proportions are retained by the azote, it is susceptible of easy decomposition, and of producing very positive effects with combustible bases. Sulphur, phosphorus, and charcoal, decompose it with facility, and if they be perfectly dry and warm, the action goes on with so much rapidity as to cause them to take fire. The same effect is produced by the essential oils, and large quantities of nitric oxide gas are evolved. Tin, copper, zinc, bismuth, and many other metals attract its oxygen with great energy, and when the acid is poured upon some of them in their liquid state, it is said they will be inflamed. Some of the metals will even decompose this acid when united with the salifiable bases. If moistened nitrate of copper be rolled up in tin-foil, the acid in the salt will be decomposed, and its oxygen, or at least a portion of it, will be transferred with so much rapidity to the tin as to cause the production of heat and light. Nitric acid and spirit of wine also act upon each other, a violent effervescence takes place, and nitric ether is first disengaged, followed by nitric oxide gas.

Nitric acid and the supporters of combustion do not appear to act upon each other.

At a red heat it is decomposed by hydrogen gas, nitric oxide and water constituting the results.

CCCXXXIX. When 2 parts of nitric acid are mixed with 1 of muriatic acid, the mixture soon acquires an orange colour, minute bubbles of gas occasionally rise to the surface, and the liquid gives out a strong odour of chlorine. In this state it constitutes the celebrated Aqua Regia of the Alchemists, the Nitro-muriatic acid of modern chemists. It is easy to per-

ceive the actions which must take place, and the changes which result from this mixture. The hydrogen of the muriatic acid partially decomposes the nitric acid, attracts from it 1 proportion of oxygen and forms water; the nitric acid is converted into nitrous acid gas, and the basis of the muriatic acid or the chlorine is evolved, so that this liquid must be composed of water, chlorine, and nitrous acid gas. It is easy to calculate the quantity of chlorine produced in nitro-muriatic acid, by the doctrine of definite proportions. For every 101 parts in weight of nitric acid, equivalent to 118 parts in weight of hydro-nitric acid decomposed, 67 parts of chlorine must be produced.* It is a solvent of many of the metals, and particularly of gold, which resists the other acids, hence the name bestowed upon it by the Alchemists. The active ingredient in it is the chlorine, and it forms with most of the metals the salts, which in the old theory were called *muriates*, but in the new are considered as *chlorides*.

Nitric acid does not act upon iodine, but combines and forms with oxiodic acid a peculiar compound. It decomposes the hydriodic acid, and the iodides or iodurets of the metals, and restores the base to its simple state.

It combines with the salifiable bases, and forms important salts, which are called *Nitrates*.

CCCXL. Mr. Cavendish, who first composed this acid by direct experiment, stated the relative weights of oxygen and nitrogen in the proportion of 72.2 of the former to 27.8 of the latter. Sir H. Davy in his Researches found them in the ratio of 70.5 and 29.5. But in his Elements, this acid is regarded as consisting of 4 volumes of nitric oxide and 2 of oxygen, which, when condensed in water, absorb 1 volume of oxygen; and then the weights of the respective elements will be 74.13:25.87. M. Gay-Lussac has endeavoured to show that nitric acid is a compound of 1 volume of azote with 2.5 volumes of oxygen, and the same conclusion may be drawn from Dr. Wollaston's experiments, and the amount of the

* Davy — Journal of Science and the Arts, vol. i. p. 67.

elements by weight corresponds within a few fractions with that of Sir Humphry Davy. It may be concluded, therefore, that pure nitric acid is a compound of 1 proportion of azote 13, and 5 proportions of oxygen 37.5, and it will be represented by 50.5. But this acid always contains water with which it must be chemically combined, and when of the specific gravity of 1.5, it may be supposed to contain 2 proportions of that compound, which will be designated by 17. The representative number, therefore, of liquid nitric acid, specific gravity 1.5, will be $50.5 + 17 = 67.5$. These calculations are upon the supposition that the water as such exists in this acid. But it is not certain that this is the case; its elements may be combined with the azote and oxygen so as in fact to form a compound of oxygen, hydrogen, and azote, and Sir H. Davy considers it as simply an expression of facts to say, that nitric acid consists of 6 proportions of oxygen, 2 of hydrogen, and 1 of azote;* or, according to the mode of expressing proportions in this work, of 6 of the first, 1 of the second, and 1 of the third. According to this view, the constitution of the other acids, in which water has been supposed to act the part of a base, must be analogous, such, for example, as the chloric, and the sulphuric. This opinion wants confirmation; but if it should be adopted, it will open to the chemist very different views of the constitution of saline compounds.

Nitrous acid.

CCCXII. When nitric oxide gas is transmitted through colourless nitric acid, a combination takes place between them and the acid becomes coloured, the kind of tint depending upon the proportion of the nitric oxide. Nitric acid, as has been observed, when first distilled from nitre, exhibits a yellowish red colour, and has been supposed to contain less oxygen than the nitric, and to form peculiar salts with the

* Journal of Science and the Arts, vol. i. p. 288.

salifiable bases, whence it was called Nitrous acid. One of these salts is nitre after it has been exposed to a red heat; oxygen is given off, and it is obvious that the remainder must contain a smaller proportion of that element. Hence the nitric acid has been inferred to be converted into nitrous acid, and the salt is called a nitrite. According to Sir H. Davy, the colour of the saturated solution of nitric oxide in nitric acid is a greenish blue, and it contains 84.6 parts of acid, 8 of nitric oxide, and 7.5 of water. The order observed in these colours as the saturation proceeds is as follows, pale yellow, bright yellow, dark orange, light olive, dark olive, bright green, blue green.* The production of the green may be observed when a piece of pure silver is immersed in nitric acid. The bulk and volatility of the acid increase with the proportion of nitric oxide, and according to Priestley, when saturated it acquires the form of a very dense vapour, the odour of which is exceedingly suffocating, and which is not very easily condensed by water. From these facts it would appear that nitrous acid is a mixture, or at most a loose compound of nitric oxide and nitric acid; they combine also in various proportions, and it is impossible to say to which should be applied the name of nitrous acid. In fact, according to this view of its composition, such an acid does not exist, and the salts which are called nitrites may be conceived with Sir H. Davy, to be compounds of bases with nitric acid and nitric oxide.

It is affirmed, however, by M. Gay-Lussac, that a true nitrous acid may be obtained by the distillation of dry and neutral nitrate of lead, and condensing the vapour in a receiver surrounded by ice. The product of this operation has been examined both by him and M. Dulong. It is a liquid, which between 59° and 82° Fah. is of an orange colour; of a light yellow at 32° , almost colourless at 18° , and perfectly transparent at -4° . It has a very strong odour, and acts upon the tongue like a caustic. Its density is 1.451, and it

* Researches, p. 37.

reddens vegetable colours. It stains, and even disorganizes the skin. Nitrous acid boils at the temperature of 82° Fah. and diffuses itself through the air in red vapours.

It appears, according to the experiments of M. Dulong, to be a compound of 2 volumes of oxygen and 1 of azote, and to consist by weight of 100 of the former, and 43.90 of the latter.* Hence, according to the system adopted in this work, it is to be considered as composed of 4 proportions of oxygen 30, and 1 of azote 13, and it must be represented by 43. Now these are the proportions of the elements in nitrous acid gas, and they must, therefore, be regarded as the same substance, the latter perhaps existing in combination with a small quantity of water.

CCCXLII. No effect results from the direct mixture of azote and chlorine; but they have an affinity for each other, and by an indirect method may be combined, forming a compound which exhibits very extraordinary properties. This compound was discovered in 1812 by M. Dulong. Its properties were soon afterwards described by Sir H. Davy,† and his paper was followed by an elaborate memoir on the subject by Mess. Porrett, Wilson, and Kirk.‡ It was called by Sir H. Davy *Azotane*, but it may be correctly indicated by the name of

Chloride of Azote.

It may be formed with great facility by inverting a jar, containing from 8 to 16 cubic inches of chlorine, in a saturated solution of either of the ammoniacal salts mentioned below.

* Thenard. *Traité de Chimie*, t. i. p. 599.

† *Philos. Trans.* for 1813, pp. 1, and 242.

‡ *Nicholson's Journal*, vol. xxiv. p. 180.

Sulphate of Ammonia

Phosphate do

Muriate do

Nitrate do

Oxalate do

Muriate of zinc with excess of ammonia.

Muriate of ammonia and iron by sublimation.

But it is not produced in solutions of carbonate of ammonia, triple muriate of platina and ammonia, or sulphate of copper with excess of ammonia. It was also found, that its formation was prevented by the presence of sulphur in solution in ammonia, or in powder in the receiver, by charcoal in fine powder, by carbonic acid equal in volume to one third of the chlorine, and by hydrogen gas in an equal volume.

The most convenient liquid upon the whole is solution of muriate of ammonia. The process may be conducted at, or a little above the temperature of the air. A vessel of the capacity above mentioned, and containing chlorine, is inverted in a bason or convenient reservoir containing a saturated solution of sal ammoniac, an absorption of the gas immediately takes place, the liquid rises, and when it occupies about $\frac{1}{4}$ of the receiver, a thin film of an oily appearance will be observed upon different parts of the surface; as the action proceeds, so much of this substance will be formed as to cause it to collect in one or two flattened globules which sink into the reservoir. These globules disappear on agitating the solution in which they are produced, and even when they are long in contact with it. They must, therefore, be speedily removed, and the most convenient method for collecting the matter is to make use of a small syringe of glass, care being taken that the piston is not lubricated with any oily, fatty, or resinous substance.

CCCXLIII. The chloride of azote has the following properties. It is a transparent liquid of the colour of olive oil, but more fluid, of a disagreeable odour, and so pungent that

it affects the eyes in a very painful manner. Its action upon the lungs is less distressing than that of chlorine. It evaporates rapidly on exposure to the air. The specific gravity of this chloride is 1.653, and it is a non-conductor of electricity.

The elements of this compound are united with a very feeble affinity. When separated, they immediately assume the elastic form, and as this separation takes place usually with rapidity, it is followed by a violent explosion. Hence, from its tendency to decomposition, the variety of substances by which it is produced, and the extreme violence of the repulsion, great care is necessary both in its collection and examination. It should never be tried in larger quantities than one grain. When a globule no larger than a mustard seed comes into contact with oil of turpentine, with any of the fixed, or animal oils, with the compounds of phosphorus, with naphtha, mineral oils, solution of pure ammonia, or the metallic soaps, it is immediately decomposed with an explosion, the force of which is superior even to that of the ammoniacal fulminating silver. The velocity of its action, according to Davy, is likewise greater. The greatest attention, therefore, is necessary in the preparation of this dangerous compound, to prevent it from coming into contact with the surfaces of the vessel. Even with this precaution, spontaneous explosions without any manifest cause sometimes take place, and as the vessel or tube in which it is contained is always rent asunder, much caution should be used on the part of the experimenter. It also explodes when exposed to heat. The cause of the sudden decomposition and detonation when the temperature is not suddenly increased, appears to be the affinity which exists between chlorine and hydrogen; and as all oils, resins, and fatty substances contain hydrogen as one of their constituent elements, we can readily account for their influence in promoting the decomposition. The results are azotic and muriatic acid gases.

The theory of its formation is simple. Ammonia is a compound of hydrogen and azote, and in sal ammoniac it is

combined with muriatic acid; when chlorine is brought into contact with the solution of this salt, one portion unites with the hydrogen and forms muriatic acid, and the other with the azote, to produce the chloride.

CCCXLIV. From the experiments of Sir H. Davy, the chloride of azote is a compound of 4 volumes of chlorine and 1 of azote, or by weight of 91.25 of the former, and 8.75 of the latter; and it would be represented by $134 + 13 = 147$. Mess. Porrett, Kirk, and Wilson have drawn a different conclusion. In analyzing 0.625 of a grain, the products amounted to .0735 of azote, and .3725 of chlorine; hence, there was a deficit of .1791 of a grain, and the compound must have contained a third constituent, which appeared to be hydrogen. They therefore state the composition as follows.

Cub. inch.	{	.7245	chlorine gas	-	-	0.54575 grain.
		.2447	azotic gas	-	-	0.07350
		.2301	hydrogen gas	-	-	0.00575
		<hr/>				<hr/>
		1.1993				0.625

The condensation in the compound amounts to $\frac{1}{777}$ of their volume. It is difficult to conceive, however, from the strong attraction of the chlorine for hydrogen, and the rapidity with which the decomposition is produced when it comes into contact with bodies containing it, that this element should exist in the chloride; and if it were a binary compound of azote and muriatic acid, it would be equally difficult to account for its violent action with inflammable bodies. These chemists make the supposition, that the hydrogen may be combined with oxygen in the form of water, but they regard it as improbable, and have shown with much ingenuity, that a quaternary compound of oxygen, hydrogen, azote, and chlorine, would exhibit properties differing from those which are characteristic of this singular body. It is therefore most probable that the analysis of Sir H. Davy is correct, and that

it is to be considered as a chloride, or a binary combination of chlorine and azote.

CCCXLV. Azote has the property of combining with iodine and of forming an iodide, which was discovered by M. Courtois. It is prepared by immersing a quantity of iodine in a strong solution of pure ammonia, it is soon changed to a brownish black, and then constitutes the compound in question. It evaporates on exposure to the air. It is characterized by its disposition to decomposition, and the violence with which its elements separate from each other. It explodes with great violence on exposure to heat, and the same effect takes place even on slight friction. The proportions of the azote and iodine in this compound have not been very accurately determined. According to M. Gay-Lussac, when it is exploded in a close vessel, the only products are azote and iodine.

Ammonia.

CCCXLVI. With hydrogen, azote forms an important compound which exists when pure in the form of gas, and is known by the name of *Ammonia*. It was discovered, and some of its properties were ascertained by Dr. Priestley. M. Berthollet first determined its composition with precision. Ammonia cannot be formed by bringing the two gases into contact, for the elastic state opposes an obstacle to their combination; but if hydrogen at the moment of its disengagement from bodies, or in what has been called its *nascent* state, be presented to azotic gas, the union is immediately effected. Hence if iron filings moistened with water be immersed in nitrogen gas, the hydrogen which results from the decomposition of the water combines, as it quits the oxygen, with the azote, and ammonia is the result. The converse of the experiment, however, does not succeed, for this compound elastic fluid is not formed when nascent azote comes into contact with hydrogen in the form of gas. Ammonia may also be

formed during the mutual action of some of the metals, particularly iron and tin, upon nitric acid diluted with water; for the affinity of these metals for oxygen is so powerful, that it causes the decomposition both of the acid and the water, the nitrogen of the one and the hydrogen of the other immediately unite, and form this compound which remains in the liquid, combined with a portion of the acid. If lime in sufficient quantities to neutralize all the acid be added to the solution, the odour of ammonia will become perceptible, and by inverting a tall glass jar, previously moistened on the inside with a few drops of liquid muriatic acid, over the vessel, white vapours composed of muriate of ammonia will be immediately formed. Gaseous ammonia is always obtained for experiment by an indirect method, which consists in decomposing some of its saline compounds, and particularly the muriate, by quick-lime. For this purpose, 1 part of sal ammoniac is mixed with 2 parts of recently slaked lime, the mixture is put into a small retort connected with the mercurial apparatus, and exposed to the heat of a spirit-lamp. Unless the materials be dry, a quantity of water distils over, and to prevent it from passing into the receiver, the neck of the retort should contain some bibulous paper.

CCCXLVII. Ammonia obtained over mercury is a permanently elastic, invisible fluid, of an acrid, alkaline taste, and of an highly pungent and suffocating odour, producing, when respired, cough and some temporary difficulty of breathing. It is not so injurious to the lungs as chlorine. Its specific gravity, atmospheric air being 1.0000, is, according to Allen and Pepys, 0.5960, and 100 cubic inches weigh 18.18 grains. Exposed to a degree of cold equal to -56° of Fah. it is condensed into a liquid which is nearly inodorous; an effect which has been ascribed by Dr. Murray to the presence of a minute quantity of water in the gas.

It is incapable of supporting combustion, or animal existence. It is slightly combustible, and when mixed with atmospheric air and fired, it burns with a pale yellow flame.

The gas is in fact decomposed, the hydrogen combining with the atmospheric oxygen, and forming water, while the nitrogen is evolved in its simple gaseous form. If pure oxygen be employed, the combustion is more brilliant, and if the mixture be made in a tube over quicksilver, and be inflamed by the electric spark, an explosion takes place. This effect is produced when the proportions are 3 of oxygen to 1 of ammonia, or 3 of ammonia to 1.4 of oxygen. When the ammoniacal gas is kindled as it issues from a small tube, and introduced into oxygen gas, it burns slowly.*

The taste of ammonia, as has been observed, is similar to that of potash and soda, it gives a green tinge to blue vegetable colours, and combines with, and neutralizes the properties of acids. Hence, it has been commonly known by the name of the *Volatile Alkali*.

CCCXLVIII. A very powerful attraction subsists between this gas and water, and if a tall glass vessel filled with it, have its mouth immersed under the surface of that liquid, an immediate condensation of the gas takes place, a vacuum is formed, and the water is pressed into it with great velocity. If a few drops of water be introduced into ammonia contained in a long tube standing over quicksilver, the same effect is produced, and the mercury rises quickly to the upper end. Ice condenses this gas with the same facility, is almost immediately melted, and the temperature falls, a proof that the capacity of water is greater than that of ammonia. At the temperature of 50° , the barometer standing at 29.8, water absorbs 670 times its volume of this gas, and the specific gravity of the liquid is lowered to .875. The following table, from the experiments of Sir H. Davy, exhibits the amount of ammonia by weight in solutions of different specific gravities.

* Murray's Elements of Chemistry, vol. i. p. 315. 4th ed.

100 parts of spec. grav.		Of ammo- nia.
0.8750	contain	32.5
0.8875		29.25
0.9000		26.00
0.9054		25.37
0.9166		22.07
0.9255		19.54
0.9326		17.52
0.9385		15.88
0.9435		14.53
0.9476		13.46
0.9513		12.40
0.9545		11.56
0.9573		10.82
0.9597		10.17
0.9619		9.60
0.9692		9.50

This aqueous solution of ammonia is generally formed in Woulf's apparatus. It is transparent and colourless, and exhales the odour which is characteristic of the gas itself. The solution is known by the name of Liquid ammonia. On exposure to heat, the ammonia re-assumes the elastic form, and at 212° , the whole of the gas passes over unaltered.

CCCXLIX. Chlorine and ammonia act rapidly upon each other. When two or three bubbles of the former are introduced into a quantity of the latter standing over quicksilver, the mixture immediately takes fire, and burns with a lively white flame. Some care is requisite in this experiment, for if the gases be mixed in considerable quantities, an explosion takes place. The heat and light produced are the consequence of the decomposition of part of the ammonia, its azote is evolved, and its hydrogen combines with the chlorine forming muriatic acid, which immediately unites with the remaining undecomposed ammonia to produce a muriate. Hence the vessel in which the experiment is conducted always becomes

filled with white fumes which soon condense upon the internal surface in the form of a crystalline solid. Even the aqueous solution of ammonia when concentrated is said by Mr. Cruickshanks to be inflamed when added to chlorine. Ammonia is also decomposed by iodine, but not so rapidly, hydriodic acid and iodide of azote are formed.

No change takes place when hydrogen and ammonia are mingled.

CCCL. Ammonia unites readily with the acids, neutralizes their properties, and forms peculiar crystallizable salts.

Chlorate of ammonia may be formed by saturating chloric acid with liquid ammonia, or, according to M. Vauquelin, with carbonate of ammonia. When crystallized, it is in the form of fine needles, which have a taste exceeding sharp, and are volatile. It detonates when placed upon a hot body, and gives out a red flame. Exposed to heat in a close vessel it is decomposed, and converted into chlorine and azote, with a little oxygen gas or oxide of azote. At the same time a small quantity of muriate of ammonia is formed.

CCCLI. The salt formed with muriatic acid is much more important. It exists native, and derives its name of *Sal Ammoniac* from the circumstance of its having been found near a temple in Africa dedicated to Jupiter Ammon. When equal volumes of ammoniacal and muriatic acid gases are mingled together in a close vessel, dense white vapours are formed, a total condensation takes place, and the product of their union is soon deposited in the form of a fine white powder. When collected, dissolved in water and crystallized, it has the following properties. It appears in the form either of long 4 sided pyramids, or of plumose crystals, according to the extent to which the evaporation has been carried. Its primitive form, according to Haüy, is the octoedron, and its integrant particle, the tetraedron. It is soluble in water, requiring at the temperature of 50° , about $3\frac{1}{2}$ times its weight, and at 212° an equal weight of that liquid for its solution. Exposed to the air, it is slightly deliquescent. During its solu-

tion in water, it sinks the temperature about 17° . Its taste is saline and somewhat acrid. Exposed to heat it sublimes without decomposition. It is decomposed by nitric acid, and nitro-muriatic acid is formed.

From its mode of formation, it is obviously composed of 1 volume of ammonia and 1 of muriatic acid. Hence it consists of

	Prop.			Atoms.			Weight.
Ammonia	-	1	-	-	1	-	31.49
Muriatic acid		1	-	-	1	-	68.51
		<hr/>			<hr/>		<hr/>
		2			2		100.00

and it may be represented by $34.5 + 16 = 50.5$.

The muriate of ammonia, or sal ammoniac of commerce, is never obtained by the direct mixture of its constituent parts. The soot of coal is macerated in water for some time, and the liquid when drawn off and evaporated affords a salt called sulphate of ammonia. This is mixed with common salt, put into a vessel of a globular form, and exposed to heat. The salts mutually decompose each other, sulphate of soda remains at the bottom of the receiver, while the muriate of ammonia, being volatile, rises in vapour and is condensed upon the upper surface. It appears, therefore, in the form of dense crystalline masses, white with a shade of red, which has been attributed to the presence of oxide of iron. Its other properties are the same as those of the crystallized muriate. In fact, by solution in water, filtration and evaporation, it may be obtained in crystals, the figures of which are such as have been already described.

Sal ammoniac is employed in the arts, and in the practice of medicine.

CCCLII. Ammonia combines readily with nitric acid, forming a nitrate, the description of the properties of which has been in some measure anticipated. The usual mode of obtaining this salt is to dilute nitric acid with 5 or 6 times its

bulk of water, and to add to it, by degrees, solid carbonate of ammonia, until the effervescence ceases. The liquid is evaporated until a pellicle appear upon its surface, the heat is then withdrawn, and when the vessel is cooled, the salt will be found crystallized in long and slender prismatic needles. As the carbonate of ammonia of commerce often contains muriate of soda, or of ammonia, the nitrate, when nitrous oxide is to be procured from it for the purpose of respiration, may be obtained in a purer state by saturating the nitric acid with the liquid carbonate, which is formed by the mixture of pearlash and sal ammoniac with water, and subsequent distillation.

The form of the nitrate of ammonia is dependent upon the extent to which the evaporation has been carried. When the water has been slowly withdrawn, it appears in the state of 6 sided prisms, terminated by long 6 sided pyramids. If the evaporation have been conducted at 212° , the crystals are channelled and have a fibrous texture, or assume the appearance of long, soft, and elastic threads. When the heat has been higher, it concretes into a dense white crystalline mass.

The taste of the nitrate of ammonia is at first saline and acrid, afterwards cooling. Its specific gravity is 1.5785. It is extremely soluble in water, and on exposure to the air, deliquesces and becomes liquid. When exposed to heat the compact suffers little or no change below 260° ; at temperatures between 275° and 300° , it sublimes slowly without decomposition, and without becoming liquid; at 320° , it melts, part is decomposed and part sublimes, but if the temperature be raised to between the 340° and 480° of Fah. it is rapidly decomposed. The prismatic and fibrous nitrates become fluid at temperatures below 300° , and undergo ebullition between 360° and 400° without decomposition. They are indeed capable of being heated to 430° without decomposition or sublimation, until a certain quantity of their water is evaporated; at temperatures above 450° their elements enter into new arrangements without previously losing their water of

crystallization.* When the heat is augmented above these points, both species of nitrate are decomposed with great rapidity, the nature of the products is different, and if the temperature be allowed to rise as high as 750° or 800° , a luminous appearance takes place in the retort, which is immediately followed by an explosion. When the temperature of the compact is between the 350° and 450° , and that of the fibrous about 400° , they are decomposed, and the only products are nitrous oxide gas and water. It will be recollected that ammonia is a compound of azote and hydrogen, and nitric acid of azote and oxygen; the balance of affinities between the elements of the two compounds is so delicate that a temperature of 400° subverts them, the hydrogen of the ammonia combines with 1 proportion of the oxygen of the acid and forms water, its azote with the nitrous gas produces the nitrous oxide. If the decomposition be conducted at a temperature much above this point, the order of attractions is altered, and the products are nitrogen, water, nitrous acid vapour, and nitrous gas.† For the production of large quantities of nitrous oxide, Sir H. Davy recommends that the fibrous nitrate should be employed. This salt undergoes no decomposition until the greater part of its water is evaporated, and in consequence, at the commencement of that process, is uniformly heated.

From the large quantity of oxygen contained in this salt, and the facility with which it is decomposed, its action upon combustible substances is analogous to that of nitre. When thrown upon live coals, it is rapidly decomposed with a peculiar noise which is characterised by the term *deflagration*, and by communicating oxygen to the inflammable body both its heat and light are increased. Hence this salt when first known was called *Nitrum flammans*.

According to Sir H. Davy, the nitrate of ammonia contains from 69.5 to 74.5 of nitric acid, from 18.4 to 19.8 of ammonia, and from 12.1 to 5.7 of water, according as the prismatic, the

* Davy's Researches, p. 85. † Ibid, p. 116.

fibrous, or the compact is the subject of the analysis. It may be considered as composed of 1 proportion each of the acid and base, and may be represented by $50.5 + 16$, or 66.5 .

CCCLIII. The composition of ammonia was first accurately ascertained by M. Berthollet. By passing it slowly over the surface of porcelain heated to ignition, it was decomposed into azote and hydrogen, in the proportion of 1 volume of the former to 3 volumes of the latter, which in the gas are condensed to 2 volumes.

It may also be decomposing it mixed with oxygen over mercury by the electric spark; the products are water and nitrogen gas. From these facts it has been concluded that it is a compound of

	Prop.	Atoms.	Weight.
Azote - -	1 - -	1 - -	81.26
Hydrogen -	3 - -	3 - -	18.74
	<hr/> 4	<hr/> 4	<hr/> 100.00

Its representative number will therefore be 16.

Nature of Azote or Nitrogen.

CCCLIV. The basis of this gas has never been obtained in an insulated form, nor has it ever been proved to consist of more than one element. Yet there are circumstances connected with nitrogen and some of its compounds, which have led to much curious and interesting speculation.

In the year 1808, Mess. Hisinger and Berzelius discovered that when a globule of mercury deposited in a cavity made in a mass of moistened muriate of ammonia, or any ammoniacal salt, was negatively electrified by a powerful voltaic battery, it rapidly increased in bulk, lost its fluidity, acquired the consistence of soft butter, and exhibited solid, arborescent crystals, shooting from its surface. This substance has all the characters of an amalgam, or a compound of a metal with quick-

silver. It effervesces when thrown into water, gives off hydrogen, and ammonia is found in the liquid. Exposed to the air, it becomes perfectly fluid, evolves the odour of ammonia, and quicksilver alone remains. The same compound may be formed more expeditiously by a method stated by Sir H. Davy, which consists in previously forming an amalgam of mercury with a small proportion of potassium, and placing it in contact with a moistened ammoniacal salt; it soon increases to 8 or 10 times its original volume, becomes a soft solid, and may be preserved for a longer time than that which is produced by the agency of voltaic electricity.

The effect upon the specific gravity of the mercury is very remarkable. According to Sir H. Davy, the metal gains by this process only $\frac{1}{12000}$ of its weight, yet its gravity is so far diminished, that instead of being more than 13, it is only 6 times heavier than an equal bulk of water. According to M. M. Gay-Lussac and Thenard, the weight gained is equal to 0.0007.

The mode in which this compound is formed, the curious properties it exhibits, and the phenomena of its decomposition have given rise to much refined theory. After the process, the compound presents all the characters of an amalgam, and as it is a property of the metals alone to form such combinations with quicksilver, the conclusion would appear to follow that the basis of one or both of the constituents of ammonia is of a metallic nature. But the amalgamating substance has as yet resisted all the attempts which have been made to obtain it in an insulated form. When exposed to heat, hydrogen and ammonia are disengaged, and the mercury resumes its original weight and volume. It has been inferred by some that the basis of ammonia is metallic, and to this element they have given the name of *Ammonium*. Professor Berzelius considers ammonia as an oxide of a compound radical, that is to say, a combination of oxygen with a basis constituting hydrogen, and of oxygen with the basis of azote, to which he has given the name of *Nitricum*. Azotic gas, according

to this chemist, is a compound of 49.32 parts of nitricum and 55.66 of oxygen ; and the amalgam on this hypothesis is composed of mercury, and the radical, either of ammonia, or of azote.*

On the other hand, M. M. Gay-Lussac and Thenard conclude from their experiments, that the amalgam consists of mercury united with ammonia and hydrogen ; and they account for the diminution in the specific gravity of the metal upon the apparent fact that these substances are scarcely more condensed than when in the elastic form.† It is evident that the real nature of this compound cannot be determined, until the constitution of azote and of hydrogen has been demonstrated.

CCCLV. With regard to the nature of azote, both analogy and experiment appear to favour the supposition that it is not simple. Its tendency to combination is comparatively slight, it is generally united to other substances by a feeble affinity, and the compounds into which it enters are easily decomposed. Experiments made some years ago by Weiglieb and Goetling, and by Dr. Priestley, seemed to prove that water on being transmitted in the state of vapour over the ignited surfaces of glass, porcelain, earthen-ware, pipe-clay, quartz, and other substances, disappeared, and that azotic gas was the only product. Hence, Dr. Priestley concluded that water was the ponderable basis of nitrogen and hydrogen. Girtanner also drew the conclusion from experiments of the same nature, that azote is water deprived of a portion of its oxygen.‡ These experiments were repeated by the Dutch chemists, and by M. M. Berthollet and La Grange, and they inferred from them that the azote proceeded from the atmospheric air which penetrated through the pores of the vessels when enlarged by the action of heat ;§ and the question respecting the nature of nitrogen appeared to be decided. The later trials of Mr. Miers, however,

* Annals of Philosophy, vol. ii. p. 367.

† Annales de Chimie, t. lxxv. p. 290.

‡ Nicholson's Journal, vol. iv. 4to, p. 137. § Ibid, p. 371.

would appear to give more probability to the opinions of Priestley and Girtanner, than was once allowed. The vapour of water and sulphuretted hydrogen gas were transmitted over the ignited surfaces of porcelain or copper, and the only gaseous products were azote, and a small proportion of oxygen. The experiments appear to have been performed with precision, and their results examined with peculiar care. Taking these as the data, Mr. Miers has submitted them to elaborate calculation, and the conclusion is finally drawn, that azote is a compound of oxygen and hydrogen, containing a less proportion of the former than water. It is composed of 6 atoms of hydrogen and 1 of oxygen, or by weight of 44.4 of the former to 55.6 of the latter.*

If this view of the constitution of azote should be finally established, the arrangement of many of the most important chemical compounds will be exceedingly simplified. For, if hydrogen be considered as the radical, its combinations with oxygen will afford azote, nitrous oxide, nitric oxide, nitrous acid gas, nitric acid, ammonia, and water. But this conclusion is too formidable to be adopted at present. The fact must be clearly demonstrated before it can be used as a basis for such a classification, and though we may impeach neither the veracity, the accuracy, nor the judgment of an experimenter, his conclusions upon so important a point ought to be confirmed by others, before unlimited confidence can be placed in them.

* *Annals of Philosophy*, vol. iii. p. 4, and vol. iv. pp. 180, 260.

SECTION III.

Of Silicon.

CCCLVI. The name of Silicon has been given to the basis or radical of silex or silica, a substance which was formerly ranked among the earths, and which exists in vast abundance in nature. It is found to constitute the principal part of quartz, rock-crystal, flint, agate, &c. and to enter into the composition of immense beds and strata of rocks.

Silex may be obtained with facility by heating red hot a mass of flint or of rock-crystal, and plunging it in that state into cold water; it becomes so brittle as to be reducible to powder without difficulty; it is then mixed with three or four times its weight of potash, and exposed to a strong heat in a silver crucible. The two substances melt and form a compound, which may be dissolved by the affusion of hot water, the solution is filtered, muriatic acid is added in excess, and the liquid is evaporated to dryness. The dry mass is to be washed with pure water until it comes off tasteless, and afterwards ignited to whiteness. The result is pure silex or silica.

CCCLVII. From the action of potassium and of iron upon this substance, there can be but little doubt that it is a compound of oxygen and an inflammable base. When the first of these metals in the state of vapour is passed through it, heated to ignition in a tube of platina, the results consist chiefly of potash mixed with a dark coloured matter, which, when fused with sulphur, forms a sulphuret soluble in water. During the solution, the dark coloured particles separate, but at the same time act upon the water, decomposing it and disengaging gas, and the greater part is converted into silex. Results not however more satisfactory are obtained when the alkaline mass is heated with hydrate of potash, or in a strong solution of the same alkali.* When iron is negatively elec-

* Sir H. Davy.—Philosophical Transactions for 1814. Part i.

trified and melted by a powerful voltaic battery, and in that state brought into contact with hydrate of silica, the globule of iron procured contains a substance which affords silex during its solution in acids.* The same results were obtained by Berzelius and Stromeyer; by heating together in a furnace a mixture of silex, iron, and charcoal, a compound of iron and the basis of the silica was procured. The proportions of the substances, according to these chemists, should be 3 of iron, 1.5 of silex, and 0.66 of charcoal; they are mixed together, put into a covered crucible, and exposed for an hour to the strongest heat of a blast furnace. A combination is thus produced of iron, silicon, and carbon, and when the latter is withdrawn, the metallic globule is white and possesses ductility; it dissolves in muriatic acid giving out a larger quantity of hydrogen gas than is produced by the action of an equal weight of pure iron, and a substance remains undissolved, composed of silex mixed with iron and carbon. According to Stromeyer, the globules containing the most silicon were composed of 85.35 parts of iron, 9.26 of silicon, and 5.37 of carbon. The specific gravity of iron is diminished in proportion to the quantity of silicon with which it is combined.

From the results of these experiments, silex or silica must be considered as a compound, one of the constituents of which is oxygen, and the other an inflammable base, once supposed to be metallic, but now regarded as analogous in its nature to boron. "It appears to be neither volatile nor fusible; its oxide exerts like boracic acid a neutralizing power on the alkalis, though of a feeblor kind, and forms like boracic acid vitreous bodies with the alkaline earths; and like boron the siliceous basis in combination with fluorine constitutes a powerful acid."—"They form a class by themselves, offering a kind of link in the chain of natural bodies, when arranged according to their analogies, between carbon, phosphorus and sulphur."†

* Elements of Chem. Philos. part i. p. 362.

† Davy.

The quantity of oxygen with which silicon in its conversion into silex combines is very considerable. It is supposed by Sir H. Davy, that it cannot be much less than one half its weight; for according to his experiments, it requires more than three parts of potassium to decompose one part of silica, an estimate which approaches the calculation of Berzelius, who, from Dr. John Davy's analysis of silicated fluoric acid gas, states the quantity of oxygen to be somewhere between 45.34, and 47.75 per cent. In other researches in which the last chemist endeavoured to arrive at the proportions by decomposing a known weight of the compound of iron and silicon, and ascertaining the weight of each of the constituents, they are stated as follows:

Silicon	54.66 to 52.25	
Oxygen	45.34	47.75
	<hr/>	<hr/>
	100.00	100.00

The mean of these numbers is for silicon 53.455, and for oxygen 46.555. Stromeyer concludes that silex contains 54 per cent. of oxygen. From these analyses, from the quantity of ammonia necessary to decompose the saturated solution of silica in muriatic acid, and from its power to combine with the alkalies, it is most probable that it consists of 1 proportion of silicon and 2 proportions of oxygen, in which case its elements will be represented respectively by 16 and 15, and the number for the compound will be 31.

CCCLVIII. Oxide of silicon, silex or silica was first accurately described by Bergman. As obtained from silicated potash by an acid, and by subsequent affusion of water and ignition, it is in the form of a white powder destitute of taste and odour, but having a peculiar gritty feel. It does not adhere to the tongue, nor form a cohesive ductile mass with water. Vegetable blues are not affected by it. Its specific gravity is 2.66. It is one of the most infusible substances in nature. It remains unaltered before the common blowpipe,

and it was unaffected in the circuit of Mr. Children's immense voltaic battery. But it is incapable of withstanding the intense heat of Mr. Hare's compound blowpipe. Exposed by Mr. Silliman to an ignited stream of oxygen and hydrogen gases, it melted into a transparent vitreous globule, and I have more than once obtained the same result.

When silex has been once dried, it is perfectly insoluble in water, but if recently precipitated from its alkaline solutions, in which state it is combined with water in the form of an hydrate, it may be dissolved, though sparingly in this liquid, and in some of the acids. From these solutions it may again be procured by evaporation. When combined with water it exists in the form of a gelatinous mass, but the union is feeble, and on exposure to the air the water is gradually dissipated.

When muriatic acid is poured into a very dilute solution of the compound of silex and potash in water, no precipitation takes place, although the properties of the alkali are neutralized, and the silex is separated from it, and as the transparency of the liquid is not impaired, it follows that the oxide remains dissolved, but by concentrating the solution by evaporation, it will be deposited in the state of hydrate.

Silicated Fluoric or Fluosilicic acid.

CCCLIX. When the liquid fluoric acid prepared according to the process of M. M. Gay-Lussac and Thenard is brought into contact with glass, the former immediately assumes the elastic state, while the latter becomes corroded. The same effect is produced upon the retort in which a mixture of powdered fluor spar and strong sulphuric acid is distilled. This corrosion is owing to the combination of the fluoric acid with the silex, which forms one of the constituents of the vitreous compound, and the silex, which has thus been removed, will be found in the elastic fluid, which from the presence of this substance has acquired the name of silicated

fluoric acid. As the retort in such cases is much injured, it may be prevented by mixing equal parts of powdered fluor spar and glass, or siliceous sand, or 3 parts of spar with 1 of silex, putting the mixture into a retort, the beak of which is connected with a *mercurial* apparatus, pouring upon the materials a quantity of sulphuric acid sufficient to give them the consistence of paste, and applying a gentle heat.

The silicated fluoric acid rises in the form of gas, and passes into the receiver. This fluid was discovered by Mr. Scheele; Priestley examined some of its properties, and more lately they have been investigated with much precision by Dr. John Davy.

CCCLX. When thus obtained it is permanently elastic, invisible, of a pungent suffocating odour similar to that of muriatic acid, and of an acid taste. It converts vegetable blues to a red; and when brought into contact with atmospheric air, combines with its aqueous vapour and forms white fumes. Its specific gravity is to that of hydrogen as 49 to 1; and to that of atmospheric air as 3.574 to 1.000; 100 cubic inches weigh, according to Dr. J. Davy, 110.78 grains.

Silicated fluoric acid is incapable of supporting ordinary combustion; a lighted candle when introduced into the gas is immediately extinguished, but when potassium is immersed in it and gently heated, it becomes blue, then burns with flame, and the volume of the gas is rapidly diminished.*

It is fatal to animal life.

When brought into contact with water the gas is immediately decomposed, and the silica in the form of hydrate is deposited in a soft gelatinous state. If the beak of the retort from which the gas is issuing, be inserted under the mouth of a tall but narrow jar filled with water on the shelf of the hydro-pneumatic apparatus, the hydrate as it is separated rises in the liquid, forming a chain of fine white vesicles, and producing a pleasing experiment. The gas is not completely decomposed by the liquid, for the water becomes acid, the presence

* Gay-Lussac and Thenard, *Recherches*, t. i. p. 313.

of silex may be detected in it, and it must be regarded as an acid solution of this substance. According to the experiments of Dr. J. Davy, it appears that silicated fluoric acid is a compound of 62.4 parts of silex, and 67.6 of fluoric acid; that by the action of water, it loses about 16.66 per cent. of silex, and that the acid which remains in solution is composed of 54.56 of the base, and 45.44 of the fluoric acid.

The attraction existing between this gas and water is very powerful, one volume of the latter according to Dr. Davy condensing no less than 365 volumes of the former; so that the affinity between the two appears to be nearly equal to that of water and muriatic acid.

To the compound dissolved in the water has been given the name of *subsilitated fluoric acid*. When it is exposed to heat in a retort silicated fluoric acid is disengaged, the neck of the vessel becomes lined with hydrate of silica in a gelatinous state, and much liquid undecomposed acid passes over. Little or no silex is left in the retort at the conclusion of the experiment. Fluoric acid pure, or free from silica cannot be obtained by heating the liquid subsilitated fluoric acid in a retort, and receiving the gas over mercury, for it was found by Dr. Davy, that a portion of silex is always distilled over with it in a state of combination.

CCCLXI. When silicated fluoric acid and ammoniacal gases are mingled over mercury in the proportion of 1 volume of the former to 2 volumes of the latter, a total condensation takes place and a solid salt is formed, called silicated fluuate of ammonia, which is volatile at the heat of a spirit-lamp, and decomposable by water; the salt formed from 30 of the acid and 60 of the alkali depositing 5 grains of silex. It is composed by weight of 75.48 of silicated fluoric acid, and 24.52 of ammonia. The constituents, as stated by Dr. Davy, are 28.24 of the latter and 71.66 of the former.*

* Nicholson's Journal, vol. xxxiv. p. 88.

It appears that all the silex is not precipitated during the formation of this salt, that it is therefore to be considered as a triple compound of silica, ammonia and fluoric acid, and that the process which has been recommended for obtaining pure fluoric acid by the decomposition of this salt by sulphuric acid will not succeed.

After the precipitation of a portion of silica, during the solution of the salt in water, the liquid is to be considered as containing dissolved a subsilicated fluato of ammonia, and this salt may at once be obtained by adding ammonia to an excess of subsilicated fluoric acid. When the solution is evaporated, small, brilliant, and transparent tetradral prisms are formed, which have a pungent saline taste, and slight acid properties; they are capable of being sublimed unaltered, and are soluble in water, but not deliquescent. When the solution of this salt is evaporated in a vessel of glass, or of earthen ware, it becomes corroded, in consequence of the affinity between its silex and the fluoric acid, and by this increase in the proportion of the silica the salt is converted into a silicated fluato of ammonia.

These salts are decomposed by sulphuric acid, which occasions the evolution of silicated fluoric acid gas. The same effect is produced by muriatic acid gas; and according to Dr. Davy, the whole of the silex may be precipitated from the solution of the subsilicated fluato by ammonia, and this corresponds with the experience of M. M. Gay-Lussac and Thenard.

The liquid subsilicated fluoric acid is decomposed by ammonia when added in excess, and hydrate of silex is precipitated white and gelatinous, but a small portion remains in the state of fluato of silex. and combined with fluato of ammonia, for when the liquid is concentrated by evaporation and more of the ammonia is added, a second precipitation of the silica takes place, so that, according to M. M. Gay-Lussac and Thenard, silex may be obtained perfectly pure from the silicated fluoric acid gas by the action of the alkalis.*

* *Recherches Physico-Chimiques*, t. ii. p. 22.

CCCLXII. Fluosilicic or silicated fluoric acid, has the property of decomposing all the salts of potash ; and it has been employed with success by Mr. Wheeler to separate chloric acid from its combination with that alkali in the salt, commonly known by the name of *oxy-muriate* of potash. The acid may be prepared for this purpose, by putting into a flask the requisite proportions of powdered fluuate of lime, fine sand, and sulphuric acid, adapting to its mouth a glass tube bent twice at right angles, and bringing the orifice within one inch of distilled water contained in a glass phial, or a bottle of Woulf's apparatus. The gas, as it passes from the tube, subsides, and coming into contact with the liquid is absorbed, and a portion of silex is deposited. If the mouth of the tube be immersed under the surface of the water, it soon becomes obstructed by the precipitated hydrate of silica. The chloric acid may be obtained by the following process. Mix a warm solution of chlorate of potash with one of fluosilicic acid ; heat the mixture moderately for a few minutes, and, to ensure the perfect decomposition of the salt, add a slight excess of the acid, which may be ascertained by its property of being wholly deprived of its silica by an aqueous solution of ammonia. By this method the whole of the chlorate of potash will be decomposed, the mixture will become slightly turbid, and fluosilicate of potash will be precipitated in the form of a gelatinous mass. The super-natant liquid will then contain nothing but chloric acid, contaminated with a small quantity of fluosilicic acid ; it is to be filtered, and the whole of the chloric and fluosilicic acids to be neutralized by carbonate of barytes, and the chlorate of that earth, after having been obtained in crystals by filtering and evaporating, is to be re-dissolved in a small quantity of water, and decomposed by the cautious addition of sulphuric acid, in the manner originally recommended by M. Gay-Lussac.*

CCCLXIII. The real nature of silicated fluoric acid has not yet been unfolded. If the theory of the constitution of the fluoric

* Journal of Science and the Arts, vol. iv. p. 287.

acid, which has been supported by M. Ampere and Sir Humphry Davy, be adopted, this gas must be viewed as a compound of the bases, both of the acid and the silex; hence, when the two come into contact its formation may be explained upon the idea, that the hydrogen of the acid unites with the oxygen of the silex and forms water, while the silicon of one and the fluorine of the other enter into combination, and produce silicated fluoric acid, or as it has been called by Dr. Thomson, fluosilicic acid gas. Facts which have been already stated, (CCLXXXVII.) appear to favour this hypothesis. If on the contrary, fluoric acid be considered either as a simple substance, or as a compound of a base with oxygen, it must be presumed to unite directly with the silica, and in this case the elements of the silicated gas will be silicon, oxygen and fluorine, or fluoric acid. This subject, however, is still involved in so much obscurity, in consequence of the powerful attraction which unites the elements of fluoric acid, and the active properties of the pure acid, which require much caution to be investigated with safety, that a positive opinion in favour of either hypothesis would be premature.

CCCLXIV. Oxide of silicon or silex exists in vast abundance, and gives generic characters to a very extensive class of stones and rocks. It is found in the greatest purity in pure quartz, and when this substance is crystallized, it is commonly known by the name of *rock-crystal*. The usual form is that of a six-sided prism, terminated by six-sided pyramids, the planes of which correspond with those of the prism itself. It is often beautifully transparent, and characterized by great hardness; it resists the file, strikes fire with steel, and scratches glass like the diamond. These crystals often present a fine amethystine colour, and occasionally fine filaments of a metal, called titanium, are seen enveloped in the crystallized mass. The primitive form of rock-crystal is an obtuse rhomboid, and this form may be in a great measure developed by the process of Mr. Daniell, by immersing a crystal in liquid fluoric acid, and allowing them to remain

some time in contact.* When masses of sufficient size and transparency are obtained, they are worked into lenses for spectacles, and are called pebbles.

Silex may also be crystallized by art. It was discovered by Bergman, that when a solution of silica in fluoric acid was allowed to stand undisturbed for a long time, a number of crystals were deposited, some of which were cubes with truncated angles, but in hardness they were much inferior to the native crystals. They have also been known to be separated from a solution of silicated potash, for a liquid of this kind which contained a great excess of alkali, having been left unnoticed for 8 years, it was found by Professor Seigling on inspecting the vessel, that a quantity of crystals was formed at the surface, and some deposited at the bottom. These crystals, when examined by Trommsdorf, were ascertained to be a mixture of those of sulphate and carbonate of potash, and silex. The last were in groupes, the form of each was a tetraedral pyramid, and they were sufficiently hard to strike fire on collision with steel.†

Silex has the property of combining with some of the salifiable bases and of forming peculiar compounds, from which circumstance it was suggested by Mr. Smithson, that it might act the part of an acid. This opinion has been more strenuously supported by Professor Berzelius, and in his new arrangement or classification of minerals, great use has been made of it in establishing the composition of the silicious stones. He has given to it the name of silicic acid. The propriety and expediency, however, of considering silex as an acid are very doubtful. It wants many of the essential characters of this class of bodies, and where it approaches to them, the same properties are exhibited by substances, such as sulphur and phosphorus, which can never be considered as acid.

* Journal of the Royal Institution, No. 1.

† Nicholson's Journal, 4to, vol. i. p. 217.

In consequence of the strong affinity which obtains between *silex* and fluoric acid, the latter has sometimes been employed for the purpose of etching upon glass. In order to produce this effect, the surface of a plate of glass is coated with a thin film of wax, or of isinglass, through either of which traces may be readily formed by a pointed instrument. The article in this state is exposed to the action of the acid, by placing it over a vessel which contains a mixture of powdered fluor spar, and sulphuric acid gently heated; the acid gas coming into contact with the uncovered parts of the glass, combines with and removes the *silex*, as well probably as the alkali with which it is united, and lines more or less deep are thus formed. Were it easy to subject glass to a sufficient degree of pressure without the hazard of destroying the plate, figures of some accuracy might be readily transferred from it to paper, and this mode would possess the important advantage of preserving the engraving for an unlimited time; but the difficulties of conducting this process are such, that it is not much employed, and at present, the figures printed in this way are remarkable neither for accuracy nor delicacy.

Silex, or at least the substances into the composition of which it enters in large proportion, is of great importance in the arts. When fused in certain proportion with potash or soda, it forms the different species of glass, and exposed to heat with some of the earths it produces all the varieties of pottery ware and porcelain. It is also an essential ingredient of the mortars employed in building.

SECTION IV.

Of Boron.

CCCLXV. There is a peculiar salt brought from the East Indies in an impure state, and refined in Europe, where it is employed in some of the arts. It is known by the name of *borax*, and is composed of soda combined with a peculiar acid, called the boracic. The acid is sometimes found near volcanoes in an uncombined form, and in the state of a white crystalline solid.

This salt may be decomposed and the boracic acid obtained, by dissolving a quantity of borax in hot water, and adding to the solution by small quantities at a time, sulphuric acid until the liquid acquires a sour taste; it is then set aside, and as the solution cools, a white substance in the form of small plates is deposited. When the production of the crystals has ceased, the whole is poured upon a filtre, and the solid portion is washed with pure cold water until it comes off tasteless; the white substance is then to be re-dissolved in water and crystallized. In this state, however, it still retains a portion of sulphuric acid, from which it may be freed by keeping it in a melted state in a Hessian crucible for 15 or 20 minutes, but as it is apt to combine with a portion of the silex of the vessel, it is recommended by M. M. Gay-Lussac and Thenard, to decompose the borax by muriatic acid, and to melt the acid thus obtained in a crucible of platina. The boracic acid procured by the last mode is crystallized in very small spangles, but when it contains sulphuric acid it is in the form of large laminae.

CCCLXVI. It was ascertained in 1807, by Sir Humphry Davy, that when this substance slightly moistened was exposed between two discs of platina to the action of a voltaic battery of not less than 100 double plates, a black matter was separated at the negative pole, but the quantity was so

minute as to render it impossible to investigate its properties. Soon afterwards, the decomposition of the boracic acid was effected by M. M. Gay-Lussac and Thenard, they succeeded in obtaining its base, and in demonstrating its properties.

One part of dry boracic acid, which has been previously melted, is mixed in fine powder with two parts of the metal called potassium, the mixture is put into a copper tube, and its temperature is gradually raised to about the 300° Fah. when a violent action takes place, the mixture becomes red hot, and a minute quantity of hydrogen gas is disengaged. When the action is terminated, the contents of the tube are to be washed out with water, which is allowed to rest in a jar until the insoluble part has subsided, the liquid is then drawn off by a syphon, fresh portions of water are added, and the process is continued until the last which is drawn off is incapable of affecting vegetable colours. The remainder is then put into a glass capsule, and the water is driven off by gentle evaporation. The solid substance which remains is Boron.*

CCCLXVII. It is of a greenish brown or olive colour, opaque, destitute of taste and odour, and incapable of affecting vegetable colours. It is neither fusible nor susceptible of volatilization at a very high degree of heat. When recently prepared, it does not subside in sulphuric acid of the specific gravity of 1.844, but after exposure to a high temperature, it sinks rapidly in the same liquid. Boron is a non-conductor of electricity. It is insoluble in water, alcohol, ether, and the oils, at any temperature. It does not decompose water at 176°, though the French chemists think it probable that this action might take place at a red heat.

CCCLXVIII. Boron and oxygen do not operate upon each other at common temperatures, but if the former be heated red hot, and be brought into contact with the latter, a vivid combustion takes place, and the oxygen is rapidly absorbed. But it has been found difficult to consume the whole in one experiment, for the boron becomes covered with bora-

* Gay-Lussac and Thenard, *Rechères*, t. i. p. 297.

ic acid, which by its melting, forms an impervious coat around it, so that the mass, when broken, appears nearly black internally, and it requires frequent washings with water and burning in oxygen before the whole is converted into boracic acid. It has been found difficult to ascertain the proportion of oxygen with which boron combines during its combustion, or in other words, the quantity of this element contained in the acid. From an experiment made by M. M. Gay-Lussac and Thenard, in which, however, they placed no great reliance, and which consisted in acidifying boron by nitric acid, they infer that boracic acid contains about $\frac{1}{3}$ its weight of oxygen.* Sir H. Davy, on the contrary, conceives that from the quantity of potassium required to decompose the acid, and from the quantity of ammonia necessary to neutralize its properties, it cannot contain much less than $\frac{2}{3}$ its weight of oxygen, and he represents the compound by 160. Dr. Thomson considers the boracic acid as composed of 1 atom of boron and 3 atoms of oxygen. If 1 grain of boron combine with 1.73 grain of oxygen,† and if we suppose boracic acid to contain two proportions of oxygen, the representative number for the base will be 8.6, and of the acid $8.6 + 15$ or 23.6, and it will be composed by weight of boron 36.50 and oxygen 63.50.

CCCLXIX. Boracic acid as has been remarked, when perfectly pure, is in the form of very small scales, white and of a pearly lustre; but as obtained by sulphuric acid, it assumes the shape of comparatively large hexagonal plates, of a shining silvery lustre, and somewhat unctuous feel. Its taste is at first slightly acid, afterwards bitterish, and finally sweetish, but it acts upon delicate vegetable blues, turning them red.

Its specific gravity is about 1.4. In this state it contains a considerable proportion of water, with which it is combined in the form of hydrate, the proportion amounting, according to Sir H. Davy, to 43 per cent.

* *Rechères*, t. i. p. 307.

† Davy—*Philos. Trans.* for 1809.

When exposed to a red heat in a crucible, it first melts, then undergoes violent ebullition, in consequence of the vaporisation of its water, and finally settles into a transparent liquid, incapable of further change. When cooled, it appears in the form of a dry vitreous mass, which on long exposure to the air becomes opaque and slightly efflorescent. Its specific gravity is then about 1.8.

In the form of hydrate it is soluble to a considerable degree in hot water, this liquid at the temperature of 212° taking up about 20 parts, 15 of which are deposited as the solution cools. In its dry or glassy state, it is much less soluble. When its solution in water is distilled, a portion of the acid passes over with the aqueous vapour.

Boracic acid is also soluble in spirit of wine, and when the solution is burned, it gives to the flame a beautiful tint of green.

It combines with the salifiable bases, and forms salts which have acquired the name of *borates*.

The borate of ammonia, which is formed by saturating boracic acid with ammonia, and evaporating the liquid to a certain degree, is in the form of prismatic crystals of a sharp taste, and contains an excess of the base. It is decomposed by heat. This salt is applied to no use.

CCCLXX. From the experiments of M. M. Gay-Lussac and Thenard, it appears that boron and chlorine when perfectly dry do not act upon each other;* according to Sir H. Davy, when they come into contact, the boron takes fire, burns with a white flame, and produces a white substance which covers the internal surface of the vessel and the remaining boron. When this matter is washed, it produces boracic acid, and leaves a black substance not spontaneously inflammable in a fresh portion of chlorine, but which may be made to undergo combustion by the application of heat.† The properties of the chloride thus formed, were not examined.

* *Rechêrches*, t. i. p. 303.

† *Phil. Trans.* for 1809, p. 41.

Fluo-boric acid.

CCCLXXI. An acid possessing singular properties was discovered by M. M. Gay-Lussac and Thenard to be formed when dry vitreous boracic acid and fluor spar were strongly heated in contact. In order to obtain this compound, 2 parts by weight of the purest fluor spar, and 1 part of vitreous boracic acid, which has been recently melted, are mixed in fine powder, and put into an iron tube open only at one end, and previously surrounded with a lute; the end containing the materials is placed in a furnace, and to the other is fitted a bent glass tube leading under the surface of mercury in the mercurial apparatus. Heat is applied, and so soon as the tube becomes red-hot, thick white vapours are disengaged which are to be caught in receivers filled with quicksilver. This gas was conceived by the French chemists to be a compound of fluoric and boracic acids, and they therefore gave to it the name of *Fluo-boric acid gas*.* It may likewise be prepared, according to Dr. John Davy, by mixing together in a retort 1 part of dry boracic acid, 2 parts of fluor spar in fine powder, and 12 of concentrated sulphuric acid, and applying a moderate heat, an effervescence takes place, and fluo-boric gas is disengaged.

CCCLXXII. It is a permanently elastic, invisible fluid, of a pungent, suffocating odour, similar to that of silicated fluoric acid, and of an exceedingly acid taste. It immediately reddens vegetable blues. When brought into contact with any of the airs containing hygrometric water, it produces vapours as dense as those which result from the union of gaseous ammonia and muriatic acid; but if the airs be perfectly dry, their transparency is not impaired. Fluo-boric gas has no effect upon glass, but it acts with great energy upon animal and vegetable bodies, and like sulphuric acid decomposes and converts them into charcoal.

* *Rechères Physico-chimiques*, t. ii. p. 37.

Its specific gravity, according to Dr. Davy, air being 1.0000, is 2.3709, and therefore under mean pressure, and at 60°, 100 cubic inches weigh 72.312 grains.

Like muriatic acid, it is characterised by its very strong attraction for water, and when a vessel filled with it is opened under the surface of that liquid, it is instantly absorbed, and the water rushes in with such rapidity, as sometimes to break the receiver. The gas to produce this effect should be perfectly pure, for according to Gay-Lussac and Thenard, if it contain only 4 per cent. of an insoluble gas, the rapidity of its condensation is singularly diminished. From the experiments of Dr. Davy it appears, that water absorbs no less than 700 times its volume of fluo-boric gas; during this condensation, the temperature rises very considerably, and the liquid at the same time augments in volume, so that when fully saturated, a cubic inch of water occupies 1.697 cubic inches. In this state it is colourless and transparent, fuming, and very caustic. By exposure to heat about a fifth part of the acid is evolved in the elastic form, but the remainder is retained by so strong an attraction, that the liquid itself rises in vapour, and is condensed upon the receiver in striæ like sulphuric acid; and like that liquid it requires for its vaporisation a temperature much higher than that of boiling water.

Fluo-boric gas extinguishes the flame of a taper; but when potassium or sodium is introduced into it and gently heated, it takes fire, and burns with great brilliancy. It does not support animal life. It combines with the salifiable bases, and forms salts which are called *fluo-borates*.

CCCLXXIII. When equal volumes of this gas and ammonia are mingled in a close vessel, dense white vapours are produced, which soon condense into a solid powdery substance, which is volatile at a moderate heat. It is composed in round numbers of 80 parts of the acid gas, and 20 of ammonia. Two other compounds of these substances exist in the form of liquids, one contains 2 volumes of fluo-boric acid to 1 volume of ammonia, and therefore consists of 67 of the former, and

33 of the latter ; in the other they are united in the proportion of 1 volume of ammonia to 3 of fluo-boric acid, and the ratio by weight is 58 of the acid, and 42 of the base.

CCCLXXIV. The nature of fluo-boric acid gas was supposed by M. M. Gay-Lussac and Thenard to be demonstrated by the results of its action upon ammonia, and by the decomposition of the salt thus formed. When the solid fluo-borate was heated, a residuum was obtained consisting of boracic acid, while the salt which sublimed was found to be fluate of ammonia, united with a small proportion of borate of ammonia, hence they concluded that the gas was a compound of boracic and fluoric acids.* But immediately after they relate an experiment, the results of which would lead us to doubt the correctness of this conclusion. When potassium was heated in this gas, a brilliant combustion took place, the volume of the air rapidly diminished, and the product of the action was a solid of the colour of chocolate, of little taste, and no metallic lustre. This substance when examined proved to be composed of boron, and of a compound which, when washed with water, produced a solution of fluate of potash.† These facts are in favour of the opinion that fluo-boric gas is a compound of the bases or radicals of fluoric and boracic acids, and that the fluoric acid and its compounds are analogous to chlorine and the chlorides. If this hypothesis be adopted, fluor spar must be considered with Sir H. Davy, as a fluoride of calcium, or a compound of the base of the fluoric acid with calcium, or the base of lime ; when it is heated with boracic acid, both of them are decomposed, the fluorine is disengaged from the calcium, and the oxygen of the boracic acid taking its place, forms lime or oxide of calcium, while the radical of the acid or boron combines with the fluorine, and produces fluo-boric gas. The phenomenon observed when this air comes into contact with other gaseous fluids containing hygrometric water are favourable to this view of its constitution, for the white fumes which are re-

* *Recherches*, t. i. p. 42.

† *Ibid*, p. 48.

markably dense may consist of the boracic and fluoric acids, which result from the decomposition of this water, its oxygen being transferred to the boron, and its hydrogen to the fluorine. When the fluo-boric gas is passed into water, the same decomposition may take place, and the like substances be formed, the permanency of the liquid depending upon the energy of their affinity, and the fixity of the boracic acid. In general, says Sir H. Davy, boracic acid can only be procured from fluo-boric acid gas by the intervention of bodies which contain water or oxygen;* and its agency here may be explained upon the same principle as its action upon some of the chlorides.

CCCLXXV. Boron appears to possess an affinity for hydrogen, and a compound of this kind, which must be called *boruretted* hydrogen, was formed by Gmelin. He mixed together four parts of iron filings, and one part of boracic acid and exposed the mixture in a crucible to a strong red heat for half an hour. When the resulting mass was dissolved in muriatic acid, a gas was produced which had the odour of common hydrogen mixed with that of garlic; when fired, it burned with a reddish yellow flame surrounded by a green border, and during the combustion white fumes were produced. It has been supposed that this gas was a mixture of hydrogen with a small proportion of boruretted hydrogen.†

No compound of boron with azote has yet been formed.

Its attraction for oxygen is exceedingly strong, and at a red heat it is capable of decomposing most of the compounds containing that element; in consequence of this affinity, it is very difficult as we have shown to decompose boracic acid, and hence this basis has never been obtained in sufficient quantities to be applied to any useful purpose. The method by potassium is the only one at present known which yields boron in a state of purity, but as this metal is not always within reach of the chemist, Doberainer has proposed a pro-

* Elements of Chemical Philosophy.

† Thomson's System of Chemistry, i. p. 250. 5th ed.

cess by which it may be procured more cheaply. It consists in mixing fine powder of borax, which has been previously melted, with one tenth its weight of lamp-black, putting the mixture into a gun-barrel, and exposing it for two hours to a white heat. During this time large quantities of carbonic oxide are evolved, and when the experiment is concluded, there is found a compact mass of a greyish-black colour, which, when reduced to powder, frequently washed with hot water and finally with muriatic acid, is found to be boron mixed with a small proportion of charcoal.*

Many of the combustibles seem to possess the power of decomposing boracic acid at very high temperatures. Gmelin obtained a compound of iron and boron, by heating the metal with the acid; and a similar compound was formed by Descotils, before the nature of the boracic acid had been discovered.†

* Annals of Philosophy, vol. ix. p. 24.

† *Rechères Physico-Chimiques*, t. i. p. 306.

SECTION V.

Of Carbon.

CCCLXXVI. In a practical point of view this is the most important of all the simple inflammable elements. It constitutes the basis of fuel, and of all those bodies which are employed in the production of artificial light and heat.

The purest charcoal, obtained by passing the vapour of oils or of spirit of wine over the surfaces of ignited tubes of metal or of porcelain, or by condensing the smoke which rises during the combustion of resinous substances, has been considered as affording an example of the nature and properties of carbon. But charcoal is not perfectly homogeneous, for when consumed it leaves a small residue of foreign matter, and some degree of uncertainty still exists respecting the real nature of this substance.

CCCLXXVII. The only body in which carbon has been found to exist in a state of absolute purity is the *Diamond*. This precious stone has been known from time immemorial, and from its hardness, lustre, and high refractive power has been deservedly placed at the head of all the gems. The diamond is found in Asia and South America, crystallized in the form of the octoedron, the sides of which are convex, sometimes to such a degree as to give it a spheroidal figure. The Brazilian gem appears often in the form of the dodecaedron. Its integrant particle, according to Haüy, is a regular tetraedron. Its matrix, at least with respect to the Asiatic, is said to be a species of conglomerate rock. The diamond is generally either colourless and transparent, or of various shades of grey, but it is sometimes red, brown, green, blue, or yellow. Its lustre is resplendent, and its hardness is extreme. The file makes no impression upon its surfaces, nor can it be polished except by friction with its own powder, or with the powder of adamantine spar. The texture of the

diamond is lamellated, it may be split without much difficulty in the direction of its laminae, and it is in this way that its rude and imperfect native forms are made to assume, in the hands of the lapidary, a regular and beautiful crystal. It is characterized by its great power of refracting and dispersing the rays of light. Its specific gravity is about 3.5. It is a non-conductor of electricity, and when exposed to friction, it becomes positively electrified. It does not exhibit the property of double refraction. Exposed to heat, out of the influence of the air, the diamond bears the most intense temperature without alteration ; but if previously coloured, it becomes transparent.

CCCLXXVIII. From the fact that transparent inflammable bodies refract light in a ratio greater than their densities, Sir Isaac Newton conjectured that the diamond might consist of an unctuous matter coagulated. Even before his time the Florentine Academicians had demonstrated that this gem when exposed to the solar rays concentrated by a powerful burning glass, disappeared, or was consumed ; and its combustibility was established by the subsequent experiments of Macquer, Cadet, Lavoisier, Morveau and Tennant. M. Lavoisier was the first who performed the experiment in a satisfactory manner. He inclosed diamonds in jars filled with atmospheric air or oxygen, directed upon them the rays of the sun concentrated by a convex lens, and after they had disappeared, examined the air in the vessels. He found it to exhibit precisely the same properties as the gas which results from the combustion of charcoal ; but he concluded that a given weight of the former produced a greater amount of this elastic fluid than an equal weight of the latter. This experiment was performed in an unexceptionable manner by Morveau ; and this chemist succeeded in demonstrating the nature of the diamond in a subsequent experiment, founded upon a principle differing from that of Lavoisier, but coinciding with it in its result. A diamond was enclosed in a cavity made in a piece of pure, soft iron, a stopper of the same metal was driven

into it, and the mass was put into a small crucible which was covered, and this into a second, the space between them being filled with pure siliceous sand. The whole was exposed for some time to an intense heat. When examined, the diamond had disappeared, and the iron with which it had been in contact was converted into steel; now steel is a compound of iron and carbon, and as the diamond was not visible, and there was no source from which the carbon could have been obtained, the conclusion was unavoidable that the diamond was pure carbon. The experiments of Mess. Allen and Pepys confirmed this conclusion. Notwithstanding the satisfactory results of these experiments, the mind was with difficulty satisfied that this mineral differed from charcoal or its basis merely in the aggregation and arrangement of its particles. It was conjectured that it might contain oxygen, and a series of delicate experiments was executed by Sir H. Davy at Florence, for the purpose of detecting, if possible, some other substance in the diamond besides carbon; but they failed. It appears that during its combustion in oxygen gas it produces the same volume of carbonic acid as the same weight of charcoal, and it must therefore be considered as differing from that substance only in the crystalline arrangement of its particles, in its hardness and transparency. Carbonaceous matter in a crystallized state has been lately found by M. Gay-Lussac in a substance obtained from the furnaces of the manufactories of porcelain in Paris. It appears in the form of slender, elongated fibres, straight, or with an angular joint, rarely curved, irregularly disposed among themselves, and of a greyish colour. From his experiments he concludes that it is pure carbon in a crystallized form.*

CCCLXXIX. The substance in which carbon exists in greatest purity next to diamond is charcoal. For common purposes it is prepared by piling billets of wood in a pyramidal form, with vacuities between them for the admission of air, covering them with earth, and inflaming them. In

* Journal of Science and the Arts, vol. iv, p. 387.

consequence of the heat, part of the combustible substance is consumed, part is volatilized together with a portion of water, and there remains behind the skeleton of the wood in the form of a black, brittle, and porous body. When required pure and in small quantities for the purposes of the chemist, it may be obtained by immersing the wood in sand contained in a crucible and exposing it to heat; or more expeditiously by plunging the mass and keeping it for some time under the surface of melted lead. Lamp-black is charcoal in a state of minute division. According to the experiments of Mess. Allen and Pepys the weight of charcoal obtained from 100 parts of different woods was as follows, fir 18.17; lignum vitæ 17.25; box 20.25; beech 15; oak 17.40; mahogany 15.75.

Charcoal is a black, brittle, and porous body, the specific gravity of which varies with the nature of the wood, but in general it is about twice as heavy as an equal bulk of water. It is infusible in the strongest heat of a furnace, or of the circuit of a voltaic battery; but when powerfully electrified it appears by Sir H. Davy's experiments, that it is slowly volatilized, and gives out a small proportion of hydrogen gas.

When perfectly dry it is a conductor both of common and voltaic electricity; but its power of conducting caloric is very imperfect, for one end of a rod of charcoal may be readily held in the hand, while the other is red hot. Hence it has been employed in the construction of ice-houses, and even of furnaces.

It is perfectly insoluble in water, and the ends of stakes and timbers which were immersed in this liquid, or buried in the earth many centuries ago, are found at the present time apparently unaltered.

CCCLXXX. One of the singular properties of charcoal is the power of condensing a comparatively large volume of elastic fluid, and aqueous vapour. When exposed in a perfectly dry state to the atmosphere, it rapidly increases in weight and, according to Mess. Allen and Pepys, the aug-

mentation is owing principally to the absorption of water. They found that charcoal made from different woods gained in the course of a week as follows.

Fir	-	-	-	-	-	13 per cent.
Box	-	-	-	-	-	14
Mahogany	-	-	-	-	-	18
Lignum vitæ	-	-	-	-	-	9.6
Beech	-	-	-	-	-	16.3
Oak	-	-	-	-	-	16.5

The average increase of weight amounted to about 14 grains for every 100.

The fact that this substance will absorb large quantities of different airs has been known for some years, and Morozzo made a number of experiments for the purpose of ascertaining with precision the amount of each. His method consisted in introducing red hot charcoal, through dry quicksilver, into a tube containing the gas, and determining the proportion by the rise of the fluid in the vessel. Rouppe and Van Noorden performed the experiment in a more satisfactory manner, by allowing the charcoal to cool out of contact with the air, and without having been immersed in the mercury. More lately this subject has been prosecuted by Saussure Jun. and the following table exhibits the proportions of the different gases absorbed by 1 volume of charcoal.

Volumes.				Volumes.			
Ammoniacal gas	-	-	90	Olefiant gas	-	-	35
Muriatic acid	-	-	85	Carbonic oxide	-	-	9.42
Sulphurous acid	-	-	65	Oxygen	-	-	9.25
Sulphuretted Hydrogen	-	55		Azote	-	-	7.5
Nitrous Oxide	-	-	40	Oxy-carb. Hydrogen		5	
Carbonic acid	-	-	35	Hydrogen	-	-	1.75

From these results it appears, that the mutual attraction between charcoal and the gases varies according to the na-

ture of the elastic fluid, and that it is exerted much more strongly by the compound than the simple gases. The fact has been also established that when charcoal has been saturated with one gas, it is still capable of absorbing a second, but at the same time discharges a portion of the first; and the presence of one is inferred to favour the condensation of another, at least in cases in which they are known to have a reciprocal affinity. It was believed by Rouppe, that when gases, which exercise mutually affinities, are thus condensed by charcoal, they combine, and that water is formed from oxygen and hydrogen, and nitric acid from oxygen and nitrogen. But Saussure, who investigated this subject apparently with great care, asserts that no union of the kind is perceptible. In consequence of the condensation, increase of temperature takes place. The air which has thus been absorbed is again given out, unchanged in its properties by the exposure of the charcoal to heat. It is difficult to give a satisfactory solution of these phenomena. The attraction, of whatever kind it may be which thus causes the condensation of a gas, must be powerful, for it is superior to the tendency which its particles have to retain elasticity; yet it does not appear to be identical with that which produces intimate combination; for the chemical properties, neither of the gas nor of the charcoal, are altered. Saussure considers it as analogous to capillary attraction.

CCCLXXXI. Another equally singular and unaccountable property exhibited by charcoal is that of removing the taste, odour, and colour of a great number of bodies, particularly those which are of an oily, extractive, or mucilaginous nature. Water may be preserved pure in long voyages by previously charring the inside of the casks in which it is to be contained, and if it should become foul, it may be purified by being filtrated through dry charcoal powder. Meat may be preserved for an indefinite time by surrounding it with the powder of this substance, and renewing it every third or fourth day. In fact, it may be kept for months even with-

out changing the charcoal, provided the mass be contained in a close vessel. Common acid of tartar and saline solutions become colourless and transparent when boiled with this substance, and impure salt of hartshorn, exposed to heat mixed with charcoal, rises white and free from fœtor. It is well known also that the flavour of distilled spirits is improved by maceration, filtration, or distillation in contact with charcoal powder; and a multitude of tinctures and wines lose both their colour and their odour. It is also one of the most effectual dentrifices yet discovered. Upon what principle in charcoal these curious properties depend, it is at present impossible to say; yet some precautions are necessary to obtain its full effect. It requires to be reduced to fine powder, and to be rendered perfectly dry by previous exposure to a red heat; and if it be not immediately employed, it should be excluded from the air in well closed vessels.

Carbon combines with two definite proportions of oxygen, and forms two distinct and peculiar elastic fluids, which have acquired the names of *Carbonic oxide*, and *Carbonic acid*.

1. *Carbonic oxide.*

CCCLXXXII. This gas was discovered by Dr. Priestley, and was soon afterwards obtained by Dr. Woodhouse of Philadelphia; Mr. Cruickshanks first accurately examined its properties, and they were more completely unfolded by the experiments of M. M. Clement and Desormes, of M. Berthollet, and of the Dutch chemists. The readiest mode of procuring carbonic oxide is that proposed by Mr Cruickshanks, which consists in mixing equal parts of chalk and clean iron filings, which have been previously exposed in a separate state to a red heat in close vessels, putting the mixture into an iron hottle connected with a gazometer, or an hydro-pneumatic apparatus, and exposing it to the heat of ignition, large bulks of a mixture of carbonic oxide and carbon-

ic acid are evolved, and the latter may be separated by standing for some time over water, or more quickly by agitation with lime-water.* In this process the iron decomposes the carbonic acid contained in the chalk by attracting one proportion of its oxygen, and it is thus converted into carbonic oxide.

This gas may also be produced by heating mixtures of dry charcoal and some of the compounds of the metals with oxygen; by exposing to heat charcoal and some of the earthy carbonates; and by transmitting carbonic acid slowly over the surface of red hot charcoal contained in a tube of porcelain.

CCCLXXXIII. Carbonic oxide has the following properties. It is a permanently elastic, invisible fluid, of a slight, but disagreeable odour, and of a specific gravity equal, according to Cruickshanks, to 0.967. One hundred cubic inches weigh 30.19 grains. Its capacity for heat, from the results of M. M. Berard and De la Roche's experiments, is 1.0340 compared with an equal volume, and 1.0805, referred to an equal weight of air as 1.0000.

It is incapable of supporting combustion, and is fatal to animal life. Sir H. Davy once took three inspirations of it mixed with about $\frac{1}{4}$ of common air; the effect was a temporary loss of sensation, which was succeeded by giddiness, sickness, acute pains in different parts of the body, and extreme debility. Some days elapsed before he entirely recovered.†

It is inflammable, and when fired in contact with atmospheric air, burns with a pale and lambent blue flame, and the only product is carbonic acid. If previously mixed with the air, it slightly explodes; when oxygen is substituted, the explosion is more violent, and two volumes of the gas combine with one volume of oxygen to form two of the acid gas.

When a stream of carbonic oxide is burned under a dry bell glass containing common air or oxygen gas, no water is de-

* Nicholson's Journal, 4to, vol. v. p. 1.

† Elements, Part i. p. 303.

posited. Water takes up only about $\frac{1}{30}$ of its volume of this gas; it is not absorbed by the caustic alkalies, nor by lime-water; it suffers no change by the action of electricity.

The specific levity of this gas, compared with carbonic acid or even with oxygen, has furnished an argument favourable to the opinion of Berthollet, that it contains hydrogen as a constituent part; but this conclusion does not necessarily follow. It may rather be supposed that the vapour of carbon is lighter than oxygen. We have stated (CXIV.) that ether is lighter than alcohol, and alcohol lighter than water, yet the densities of their vapours are in the inverse order; hence, as observed by Sir H. Davy, the specific gravities of gases bear no relation to the densities of the fluids or solids from which they are formed.*

From the results obtained by exploding carbonic oxide with oxygen, it appears that it contains half as much oxygen as carbonic acid. We shall show hereafter that carbon, when oxygenized at the maximum, forms a compound containing two proportions of oxygen, and carbonic oxide, therefore, may be considered as composed of

		Prop.			Atoms.			Weight.
Carbon	-	1	-	-	1	-	-	43.60
Oxygen	-	1	-	-	1	-	-	56.40
		<hr/>			<hr/>			<hr/>
		2			2			100.00

Now $56.40 : 43.60 :: 7.5 : 5.7$, and it may be represented by $5.7 + 7.5 = 13.2$.

CCCLXXXIV. Carbonic oxide and chlorine in certain circumstances mutually re-act upon each other, combine, and form a peculiar compound. Mr. Cruickshanks found that when 2 measures of carbonic oxide and $2\frac{1}{2}$ of oxy-muriatic gas were mingled in a glass phial, which was afterwards stopped and inverted in water, on allowing the mixture to stand 24 hours, and then opening the vessel, two thirds of the gas were

* Elements, Part i. p. 305.

immediately absorbed, and the remainder disappeared by the action of lime-water. But the conclusion which may be drawn from the experiment is doubtful, as he procured his oxy-muriatic gas from muriatic acid and chlorate of potash. The compound of the two gases was discovered by Dr. John Davy;* and it was formed by the influence of light. Equal volumes of carbonic oxide and chlorine, carefully dried, were mingled in an exhausted receiver free from moisture, and exposed to the influence of direct solar light; the gases speedily acted upon each other, in 15 minutes the colour of the chlorine disappeared, and the mouth of the vessel being then opened under the surface of mercury, the fluid rushed in, and the airs were found diminished to $\frac{1}{2}$ their original volume. The residual air possessed characteristic properties, and Dr. Davy gave to it the name of *Phosgene gas*, because it was formed by the action of light. According to the principles of chemical nomenclature, it should be called

Chloro-carbonic acid.

CCCLXXXV. It is transparent and colourless, possessing an odour which partakes of those of chlorine and ammonia, and which is highly suffocating, and irritating to the eyes. As it is composed of equal volumes of the gases, its specific gravity is $2.4700 + 0.9670$, or 3.4370 compared with atmospheric air as 1.0000 ; the specific gravity of hydrogen being taken as unity, that of phosgene will be 47.5 nearly; 100 cubic inches at mean temperature and pressure will therefore weigh 104.92 grains. It gives a red colour to paper stained with litmus. When the electric spark is taken through a mixture of chloro-carbonic acid and oxygen, or hydrogen, it does not explode, but if 2 volumes of it be mingled with 2 volumes of hydrogen and 1 volume of oxygen, electricity produces a violent detonation, and the products are carbonic and muriatic acids. In

* Philos. Trans. for 1812, p. 144.

this case it appears that the hydrogen combines with the chlorine, and the oxygen with the carbonic oxide.

The attractions of chlorine for carbonic oxide and hydrogen appear to be equal.

Phosgene does not act upon azote.

CCCLXXXVI. When mingled with gasiform ammonia, a rapid condensation takes place, a white salt is deposited, and much heat is produced. In this solid, the properties of the constituents are neutralized; the salt is destitute of odour, but has a saline and pungent taste; it is deliquescent, and very soluble in water. It is decomposed by sulphuric, nitric, phosphoric, and liquid muriatic acids, but sublimes unaltered when exposed to heat in muriatic, carbonic, and sulphurous acid gases. The attraction between chloro-carbonic acid and ammonia must be strong, as 1 volume of the former condenses 4 volumes of the latter, and yet forms a neutral salt.

Phosgene gas is speedily decomposed by water, and the elements of this liquid contribute to the formation of muriatic and carbonic acids; hence in order to form and preserve this elastic fluid, it is absolutely necessary not only that the bodies of which it is composed, but also the vessels in which it is contained, should be perfectly free from moisture.

Upon the idea that chlorine is a simple body, chloro-carbonic acid will be composed of 1 proportion of chlorine 33.5, and 1 of carbonic oxide 13.2, and its relative number is 46.7. But if chlorine be a compound of muriatic acid and oxygen, it must be considered as a compound of muriatic acid and carbonic acid.

Carbonic acid.

CCCLXXXVII. If a piece of well burnt charcoal be heated red hot, and then introduced into a receiver filled with pure oxygen gas, standing over mercury, it consumes with increased splendour, frequently throwing off sparks of intense brilliancy, and finally, if the mass have not been too large, disap-

pears. If a small diamond be placed upon a stand in the same circumstances, and the rays of the sun be directed upon it through a large convex lens, it becomes surrounded with a dazzling light, appears to boil, and gradually wastes away. It was ascertained by Sir H. Davy, that this gem produces in this situation a sufficient degree of heat to continue its own combustion. This phenomenon, though rarely observed, is easily exhibited. If the diamond, supported in the perforated cup, be fixed at the end of a jet, so that a stream of hydrogen can be thrown upon it, it is easy by inflaming the gas to heat the gem, and while in that state, to introduce it into a vessel containing oxygen. On turning off the hydrogen, the diamond enters into combustion, and will remain burning until nearly consumed.*

When the air in the vessel in which either charcoal or diamond has been consumed, is examined, it will be found unaltered in volume, but entirely changed in its properties. It is now a compound of carbon and oxygen, and is known by the name of Carbonic acid. The elements are combined in it to the point of saturation.

This important body was one of the first of the elastic fluids whose properties were accurately unfolded by the researches of the chemist. Dr. Black first described it in his Dissertation *De Magnesia Alba*, published in 1754, and some years after its composition was demonstrated by direct synthetical experiments by Lavoisier. It has been known by a variety of names, of which the most familiar is that of *Fixed air*. The French chemists first designated it by the title of Carbonic acid. It exists in an uncombined form in nature; it constitutes the *choak damp* of coal mines, and is found in caverns and grottoes. It issues in a stream from the celebrated Grotto del Cano, near Naples, and as from its high specific gravity, it rarely rises above the height of 4 or 5 inches from the floor, men may enter the cave with impunity, while small animals, on coming within its influence, are suffocated.

* Journal of the Royal Institution, vol. iv. p. 155.

It is also copiously produced in the fermenting vats of breweries and distilleries ; it is evolved in the processes of respiration and ordinary combustion ; and in a combined state constitutes an essential ingredient in all the varieties of limestone. As it is retained in these compounds by a feeble affinity, it may be disengaged from them by the action of an acid or by the repulsive energy of heat. It is therefore never necessary for the production of this gas, to have recourse to the direct union of carbon with oxygen. For common purposes, it may be obtained with facility by putting marble in small fragments or in coarse powder into a tubulated retort, and pouring upon it diluted muriatic or sulphuric acid ; the marble, which is a carbonate of lime, is decomposed, its base combines with the acid added, while the carbonic acid is evolved in the elastic form. After the atmospheric air is pressed out, the beak of the retort is to be connected with the hydro-pneumatic apparatus, and the gas will then rise through and displace the water in the receiver. If the carbonic acid is not to be used immediately, it is necessary to employ receivers which may be closely stopped, for if the gas be allowed to remain long in contact with the liquid, it will be absorbed. The gas may also be obtained in a state of purity, by exposing marble, chalk, or the crystallized lime-stones in an iron bottle to a red heat.

CCCLXXXVIII. Procured by either of these methods, carbonic acid is a permanently elastic, invisible fluid, of a slight odour and acid taste. Its specific gravity compared with atmospheric air as 1.0009, is, according to M. M. Biot and Arago, 1.5196 ; and with hydrogen as 20.7 to 1. One hundred cubic inches at 60°, and under mean pressure, weigh 46.35 grains. This gas is incapable of supporting combustion, and is fatal to animal life. It appears to exert a positively injurious influence upon the system, and its respiration, even when diluted with its own bulk of atmospheric air, is followed by asphyxia and death. Sir H. Davy made the hazardous experiment of attempting to breathe carbonic acid undiluted, but it

was not successful ; it tasted acid, but it was in vain that he made powerful voluntary efforts to draw it into the lungs, for the moment it reached the entrance of the wind-pipe, so painful a spasm was caused, as to oblige him to desist from his attempts. On respiring a mixture of 3 parts of this gas with 7 of atmospheric air, the only effects produced were a slight degree of giddiness, and an inclination to sleep.* It is probable that if the unmixed gas had been breathed, the consequence would have been immediate loss of sensation and perception, and perhaps death. The fatal effects arising from the presence of carbonic acid have been too amply demonstrated by experience. It is copiously produced in the vats of breweries and distilleries, and it not unfrequently happens, that persons, who incautiously descend into them before they are sufficiently ventilated, are instantly suffocated. The same influence, though in a more gradual manner, is exerted upon those who, from ignorance or carelessness, sleep in close apartments which are heated by burning charcoal. Although in the last case, death is not immediate, yet the respiration of the gas, when diluted, appears to lessen the irritability, and weaken the powers of the muscular system to such a degree, as to render the subjects incapable of making the exertions necessary to the preservation of life. As carbonic acid is heavier than atmospheric air, it subsides when first formed to the lowest part of the room, and the author has known an instance in which two children upon the floor of an apartment were suddenly reduced to the state of asphyxia, while the attendant, who was more elevated, escaped with a slight giddiness. In cases in which apparent death has been produced by the fumes of burning charcoal, or by inhaling carbonic acid, the most effectual remedies are fresh air, and the affusion of large quantities of cold water over the surface of the body.

CCCLXXXIX. The composition of carbonic acid has been demonstrated both by burning diamond and charcoal in oxygen gas, and by the combustion of carbonic oxide.

* Davy's Researches, p. 473.

As the bulk of the air, after charcoal has been consumed, remains unchanged, it is obvious that the weight which is gained by the oxygen must indicate the amount of the carbon combined; and that this amount may be obtained by subtracting from the weight of a given volume of the acid gas, the weight of the same volume of oxygen. Now 100 cubic inches of the latter weigh 33.82 grains, and an equal bulk of the former 46.35 grains; and $46.35 - 33.82 = 12.53$, the weight of carbon in the acid. But $12.53 : 33.82 :: 5.7 : 15$, and $5.7 : 15 :: 27.33 : 72.67$; consequently, carbonic acid consists of

		Prop.			Atoms.			Weight.
Carbon	-	1	-	-	1	-	-	27.33
Oxygen	-	2	-	-	2	-	-	72.67
		<hr/>			<hr/>			<hr/>
		3			3			100.00

The same results are obtained, if the calculations be founded upon the data which are furnished by detonating carbonic oxide with oxygen. If one volume of oxygen be mixed with two volumes of carbonic oxide, and the mixed gases be exploded by the electric spark, two volumes of carbonic acid will be formed; hence this acid contains twice as much oxygen as carbonic oxide, and if the oxygen in the latter be considered as 1 proportion 7.5, the oxygen in the former will be represented by 15, and the number for the acid gas will be $5.7 + 15$, or 20.7.

The analyses of carbonic acid by different chemists approximate very nearly to each other, as may be seen in the following table.

		Carbon.			Oxygen.
Lavoisier	-	28	-	-	72
Tennant	-	28	-	-	72
Clement and Desormes		28	-	-	72
Allen and Pepys	-	28.60	-	-	71.40
Saussure Jun.	-	27.04	-	-	72.96
Gay-Lussac	-	27.37	-	-	72.63
Wollaston	-	27.38	-	-	72.62

The mean of these numbers affords 27.77 for the carbon, and 72.23 for the oxygen in 100 parts of the acid.

CCCXC. The acid properties of this gas are not very considerable. It reddens only the most delicate of the vegetable blues, and when exposed to the air, the original colour, from the evolution of the carbonic acid, is soon restored.

One of the most convenient and delicate of the tests by which the presence of this acid may be detected, is lime-water. When they are brought into contact, the lime and the acid unite, forming an insoluble compound, which before it is precipitated gives to the liquid a white and turbid appearance. Even the small quantity of carbonic acid produced in the process of respiration may be rendered evident by blowing air from the lungs through lime-water.

When a vessel containing carbonic acid is inverted with its mouth open under the surface of water, an absorption commences, and the water slowly rises to the upper surface. The condensation of the gas is effected in a much shorter time by agitation. Water at the usual temperature takes up rather more than an equal volume of the gas; but the power of absorption is proportional to the lowness of temperature, and the degree of pressure applied, so that under favourable circumstances, 3 or even 4 volumes of gas may be condensed by 1 volume of the water. When thus impregnated, the liquid acquires an acidulous taste, sparkles when poured into a glass, and from its expansive force often bursts the vessels in which it is confined. It is this gas which gives the brisk lively

taste, and power of effervescing, to champagne wine, cider, perry, and other fermented liquids. Soda-water is a solution of a small proportion of the carbonate of soda in water, and highly charged by great pressure with carbonic acid. For common purposes, the aqueous solution of the acid may be formed in Nooth's apparatus.

It appears from the experiments of Dr. Henry, that water takes up the same volume of compressed gas, as of the gas under ordinary pressure; and since the space occupied by any gas is inversely as the compressing force, it follows that the quantity of gas forced into water is directly as the pressure. Thus, if water under common pressure take up an equal volume, it will, when the pressure is doubled, absorb 2 volumes, and 3 volumes when the compressing force is equal to 3 atmospheres. The solution of carbonic acid in water possesses acid properties, and precipitates lime from its solution, the acid is again expelled from it in the elastic form by heat, by congelation, or by placing it under the receiver of an air-pump, and exhausting the air.

Carbonic acid enters into combination with the salifiable bases, and forms peculiar salts, which are called *Carbonates*.

Carbonate of Ammonia.

CCCXCI. When carbonic acid is admitted to ammoniacal gas standing over mercury, a combination immediately takes place between them, a white cloud is formed, which soon condenses into a solid, and the mercury rises in the vessel. This action is best observed in employing a long eudiometric tube. If the mixture be made in close vessels in the proportion of 1 volume of carbonic acid to 2 volumes of ammonia, the gases are totally condensed, and at the same time the temperature rises, and the white substance which is deposited constitutes the sub-carbonate of ammonia. It is a compound of some importance, and is known in commerce by the name of *Salt of*

Hartshorn. It is never obtained for the purposes of commerce by the direct union of its constituent parts; the more economical process is followed, of procuring it by the distillation of animal substances, or of a mixture of chalk and muriate of ammonia. Equal parts of this mixture are put into a vessel of a globular form; it is then closed and exposed to heat. The compounds mutually decompose each other, the muriatic acid of the sal ammoniac, and the lime of the chalk unite with each other, forming muriate of lime, which remains at the bottom of the vessel, while the ammonia of the former and the carbonic acid of the latter are disengaged, immediately unite and produce carbonate of ammonia, which from its volatility rises and is condensed upon the upper surface of the receiver.

CCCXCII. Sub-carbonate of ammonia thus obtained is in the form of a dense white crystalline solid, which exhales the odour of ammoniacal gas. Its taste is acrid and alkaline, and it gives a green tinge to vegetable blues. It is susceptible of regular crystallization, and then assumes the figure of the octoedron, but the crystals are often small and indistinct. It is very soluble in water, requiring for its solution two parts at 60°, and one part of the liquid at 120°. It is volatilized from this solution at 212°. Sub-carbonate of ammonia is volatile. It slowly evaporates on exposure to the air, and when in a phial the heat of the hand alone, as is well known, increases its pungency; it may be distilled over with aqueous vapour.

A solution of this salt is often prepared for chemical and pharmaceutical purposes by putting into a retort, 1 part each of pearl-ash and muriate of ammonia, with 2 parts of water, connecting the beak with a large globular receiver, which is kept cool, and exposing the materials to a boiling heat. The sub-carbonate is formed by decompositions and combinations analogous to those above mentioned, and it passes over into the receiver with the water. The vessels during this operation frequently exhibit upon their internal surfaces, the solid salt in the form of delicate prismatic crystals.

This salt is conceived to be a compound of 1 proportion of ammonia 16, and 1 of carbonic acid 20.7, and may be designated by 36.7.

The ammonia, it is evident, is not saturated with the acid, but it was found by M. Berthollet, that if a stream of carbonic acid were transmitted through a solution of the sub-carbonate, a combination between them took place, and another compound was formed, which was neutral. The salt may be obtained in the solid form crystallized in small 6 sided prisms, destitute of odour, and less irritating to the taste than the sub-carbonate. It is properly the carbonate of ammonia. It consists of 2 proportions of carbonic acid, and 1 proportion of ammonia, and may be designated by $41.4 + 16$, or 57.4.

The sub-carbonate is now generally considered as the carbonate; and to the salt last described is given the name of *bi-carbonate*.

Both of them are decomposed by all the acids which have been mentioned in the preceding pages, the carbonic acid being evolved in the elastic form.

CCCXIII. When carbonic acid was subjected to the action of electricity over mercury, it was ascertained by Dr. Henry that a part of it was decomposed into oxygen and carbonic oxide; and after the remaining carbonic acid was withdrawn, the electric spark again caused an union between the two substances, and reproduced carbonic acid.

Mixed with hydrogen and fired by the electric spark, the same chemist found that water and carbonic oxide were the products of the experiment.

Carbon combines neither with chlorine nor iodine. When dry charcoal is ignited to whiteness by voltaic electricity in dry chlorine gas, no perceptible action between them is exerted and they continue unaltered. This fact has furnished a strong argument against the theory of the simple nature of chlorine, for if this element be a supporter of combustion and analogous in its general properties to oxygen, we ought to expect that a combination should take place, but it is not the

case, and this theory can assign no reason for the anomaly. On the other hand, if chlorine consist of muriatic acid and oxygen, it has been said that charcoal is incapable of decomposing it in these circumstances, because water is essential to the gaseous constitution of muriatic acid, and accordingly if water be present, carbonic and muriatic acids will be formed. But this mode of explaining the circumstance is hypothetical, for the fact can hardly be considered as established that water, though it is found to exist in small quantity in muriatic acid, is absolutely necessary to its aëriform state, and the presence of this liquid may, by furnishing the elements oxygen and hydrogen, give rise to the formation of muriatic and carbonic acids.

Carbon combines with hydrogen and forms compounds, to which is applied the general name of *Carburetted Hydrogen*. It was once thought that these elements were susceptible of union in a variety of proportions, but it has since been found that they may be reduced to two species which are distinctly characterized; these are the light carburetted hydrogen, and the bi-carburetted hydrogen, or olefiant gas.

1. *Light Carburetted Hydrogen.*

CCCXCIV. This important compound has been long known. It is a production of nature, and is formed during the spontaneous decomposition of vegetable substances. It is also evolved in abundance in coal mines, in which it is familiarly known by the name of *Fire damp*, and which when mixed with atmospheric air and inflamed occasions the explosions so destructive to the lives of the miners.

It may be obtained, for experiment, in a variety of ways. 1. By the distillation of pitcoal, in which case, however, it is mixed with other inflammable gases. 2. By the exposure of the salt called acetate of potash to a strong heat. 3. By heating charcoal in its common state red hot in appropriate vessels. 4. By transmitting the vapour of water over the

surface of ignited charcoal, as in the experiment of decomposing that liquid by iron. 5. By sending the vapour of alcohol, ether, or camphor through a tube of glass, of porcelain, or of metal heated to ignition.

The most convenient method of procuring this gas is to put a quantity of charcoal, which has been exposed to the air, into an iron bottle, or an earthen-ware retort previously coated with sand and clay, to connect its beak with a gazometer or water-trough, and expose the vessel to a red heat; a large quantity of elastic fluid will be evolved, consisting of carbonic acid, with a great proportion of carburetted hydrogen. The gas which is first obtained contains most of the acid gas, the proportion continually diminishes, and toward the conclusion the inflammable air comes over nearly in a state of purity. The theory of the process is perfectly simple. Charcoal, as has been already stated, on exposure to the air, gains upon an average about 14 per cent. in weight. This increase, according to Allen and Pepys, is owing principally to the absorption of moisture. When the charcoal is heated red hot, this water, or at least a part of it, is decomposed; its oxygen combines with a portion of the carbon and forms carbonic acid, and its hydrogen with another portion, producing carburetted hydrogen; the two gases pass into the receiver, and the carbonic acid is absorbed slowly by the water with which it is in contact, or more expeditiously by agitating the mixed air with lime-water. The quantity of gas given out by charcoal thus heated is prodigiously large, for from one ounce M. Berthollet affirms that he obtained no less than 720 cubic inches. It has been inferred by Dr. Murray, that the different species of this gas contain oxygen, and he has applied to them the name of oxy-carburetted hydrogen; but later researches do not confirm his conclusion, and they are now considered as binary compounds of carbon and hydrogen.

CCCXCV. The inflammable gas from charcoal does not appear to be perfectly pure, even after having been exposed to

the action of lime-water. But carburetted hydrogen may be obtained mixed with carbonic acid and atmospheric air from stagnant water; the former may be easily withdrawn, and it is easy to make the necessary allowance for the presence of the latter. Dr. Franklin observed, that when a stick was thrust to the bottom of stagnant water in the summer season, bubbles of air rose to the surface, which might be inflamed by a lighted candle. This air has been successively examined by Mr. Cruickshanks, Mr. Dalton, and Dr. Thomson; it may be collected by filling a glass phial with water, inverting it under the surface of a pond or ditch, and supporting it upon a piece of wood or cork. To the mouth is to be attached a funnel-shaped vessel, which may be formed of thick oiled paper, and the mud below is to be stirred; numerous air-bubbles rise, and expel the water from the phial. It is then to be washed with lime-water, or solution of potash, to deprive it of the carbonic acid, which is always present in greater or less proportion. It likewise contains atmospheric air.*

CCCXCVI. Thus obtained it is a permanently elastic, invisible, inodorous, and insipid fluid, lighter than atmospheric air, but heavier than simple hydrogen; its specific gravity compared with atmospheric air being in the ratio of 0.5554 to 1.0000, and with hydrogen gas as 7.6 to 1; hence, when the barometer is at 30, and the thermometer at 60°, 100 cubic inches of carburetted hydrogen will weigh 16.88 grains.

When a lighted candle is applied to the mouth of a vessel containing this gas, it takes fire, and burns with a yellow and larger flame and more readily, than any other combustible gas, with the exceptions of olefant gas, and the vapour of ether.† When the jar is inverted over a lighted taper, the lower stratum of the gas is inflamed, but the light is extinguished.

Mixed with oxygen gas and kindled by the electric spark, it detonates loudly, and it requires for complete combustion

* Thomson's System of Chemistry, vol. i. p. 242. 5th ed.

† Memoirs of the Wernerian Society, vol. i. p. 509.

twice its volume of oxygen, and produces exactly its own volume of carbonic acid. The combustion will not take place unless the bulk of the oxygen rather exceed its own bulk, and it ceases to burn when the oxygen exceeds $2\frac{1}{2}$ times its bulk. It may be inflamed when mixed with atmospheric air in any proportion between $\frac{1}{8}$ and $\frac{1}{12}$ of the air, but if it amount to more than the former, or less than the latter, this effect will not be produced.

The composition and proportion of the elements in carburetted hydrogen may be ascertained by the quantity of oxygen required for saturation. It appears by the experiments of Dr. Henry, that 1 volume of this gas consumes by detonation 2 volumes of oxygen, and that carbonic acid and water are the only products; hence 1 volume of the oxygen combines with the carbon to form a volume of carbonic acid, and 1 volume with the hydrogen to constitute the water; now this quantity of oxygen unites with 2 volumes of hydrogen, so that the elements of carburetted hydrogen are

		Prop.			Atoms.			Weight.
Carbon	-	1	-	-	1	-	-	71.43
Hydrogen	-	2	-	-	2	-	-	28.57
		<hr/>			<hr/>			<hr/>
		3			3			100.00

It may be represented by $5.7 + 2$, or 7.7 .

CCCXCVII. The gas obtained by the distillation of charcoal, or by transmitting water over the surface of that substance heated to ignition, and from which the carbonic acid has been afterwards abstracted, varies considerably in its properties from the one just described. It has a very disagreeable odour, its specific gravity is only 0.4800, and when fired it burns with a pale blue flame. When the electric spark is passed through it for some time, a decomposition takes place, carbon is deposited, and hydrogen evolved.

Mixed with chlorine and allowed to remain at rest for 24 hours, it is decomposed, and, according to Cruickshanks,

water, carbonic acid, and muriatic acid are formed, and carbonic oxide remains.* These results imply the presence of oxygen in chlorine; but as water was present, it was probably derived from that source, the liquid having been decomposed, its oxygen combining with the carbon, and its hydrogen with the chlorine. When carburetted hydrogen is mixed with twice its volume of chlorine over mercury, and subjected to the action of the electric spark, inflammation takes place, charcoal is deposited, there ensues a considerable expansion, and about 4 volumes of muriatic acid are produced.† In this experiment, the 2 proportions of hydrogen in the combustible gas combine with the 2 proportions of chlorine, and form 4 proportions of muriatic acid.

Water absorbs about $\frac{1}{50}$ of its volume of carburetted hydrogen.

CCCXCVIII. This gas is fatal to animal existence, and when breathed, even if diluted with atmospheric air, operates upon the system with great energy. Sir Humphry Davy attempted its respiration, and his rash experiment had nearly cost him his life. Four quarts of nearly pure gas which had been produced from the decomposition of water by charcoal, and which had a very strong, disagreeable smell, were introduced into a silk bag. After a forced exhaustion, says he, of my lungs, the nose being carefully closed, I made three inspirations and expirations of the hydro-carbonate. The first inspiration produced a sort of numbness and loss of feeling in the chest, and about the pectoral muscles. After the second inspiration, I lost all power of perceiving external things, and had no distinct sensation, except a terrible oppression on the chest. During the third expiration, this feeling disappeared, I seemed sinking into annihilation, and had just power enough to drop the mouth-piece from my unclosed lips. A short interval must have passed, during which I respired common air, before the objects about me were distinguishable. On

* Nicholson's Journal, 4to, vol. v. p. 202.

† Davy's Elements, Part i. p. 307.

recollecting myself, I faintly articulated, "I do not think I shall die;" and putting my finger on the wrist, I found my pulse thread-like, and beating with excessive quickness. The subsequent effects upon his system were giddiness, extreme debility, nausea, loss of memory, deficient sensation, followed by intense head-ach, which continued for several hours.*

2. *Heavy, or Bi-carburetted Hydrogen.*

CCCXCIX. This gas was first accurately examined by the associated chemists of Amsterdam. It was observed by them to be disengaged in the process of preparing sulphuric ether. It is disengaged nearly at the conclusion of the operation, before the ether ceases entirely to be formed; and by ascertaining at this period the proportions of the materials to each other, they found that it might be obtained at once by mixing 4 parts of concentrated sulphuric acid with 1 of strong alcohol or spirit of wine. The alcohol is put into a thin tubulated retort, the body of which is deep, and upon it the sulphuric acid is poured in an uninterrupted stream. The mixture immediately grows brown, exhales a fragrant odour, and its temperature rises to about 180° Fah. The heat of a lamp is then applied, and after the formation of a small quantity of ether, a gas is liberated in considerable abundance, and may be caught over water.

Various other methods of preparing this gas have been proposed, such as transmitting the vapour of alcohol, ether, camphor, &c. over the ignited surfaces of glass or of porcelain, or of some of the native compounds of the earths, but the products are not always the same, and the elastic fluid obtained is often a mixture of the two species of carburetted hydrogen.

Bi-carburetted hydrogen, or olefiant gas, is invisible, and permanently elastic. Its odour is offensive; its specific grav-

* Researches, p. 468.

ity, compared with atmospheric air, according to Dr. Thomson, is as 0.974 to 1.0000; and with hydrogen, as 13 to 1; 100 cubic inches weigh 29.72 grains. It is incapable of supporting combustion, or animal life.

It is highly inflammable, and when fired burns with a dense and brilliant yellowish white flame, producing carbonic acid and water. When a flame is applied to a mixture of this gas and oxygen, it does not explode, but consumes rapidly with a vivid light; but if the electric spark be transmitted through a mixture of 1 volume of the gas and 3 volumes of oxygen, the result is an immediate and violent detonation. From the large quantity of oxygen required for its combustion, it obviously contains a larger proportion of carbon than the preceding species. From the experiments of Mr. Dalton and of Dr. Henry, with which those of Dr. Thomson nearly coincide, it appears that 100 of olefiant gas require 300 volumes of oxygen for complete decomposition, and that water and 200 volumes of carbonic acid are produced; but 100 of oxygen require for saturation 200 of hydrogen; whence it follows, that in this gas there are present 200 volumes of hydrogen condensed so as to occupy but 100 volumes; a fact, which is also demonstrated by heating sulphur in contact with it, for in this case charcoal is deposited, and two volumes of sulphuretted hydrogen are produced; now when sulphur combines with hydrogen, there is neither an increase nor diminution of volume, and it follows that bi-carburetted hydrogen contains two volumes of hydrogen condensed into one volume, and is composed of

	Prop.	Atoms.	Weight.
Carbon - - -	1 - - -	1 - - -	85.08
Hydrogen - - -	1 - - -	1 - - -	14.92
	<hr/> 2	<hr/> 2	<hr/> 100.00

and it may be represented by $5.7 + 1 = 6.7$.

The amount of the elements by weight coincides, within 1000, with the estimates of Saussure Jun. and of Dr. Thomson.*

When olefiant gas is mixed with rather less than its own volume of oxygen and fired by the electric spark, carbon is deposited, and the residual air occupies a larger space than before the experiment. This fact was ascertained by Mr. Cruickshanks, and after him by M. Berthollet and Dr. Thomson, the last of whom infers that the gas is not carbonic oxide, but possibly a ternary compound of oxygen, hydrogen, and carbon, and may therefore be named oxy-carburetted hydrogen.†

CCCC. Heavy carburetted hydrogen and chlorine combine with each other and form a compound, which has the external properties of oils; it was from this circumstance that the name of *Olefiant gas* was bestowed upon this species of carburetted hydrogen by the Dutch chemists. It was examined by Dr. Thomson, and subsequently by M. M. Colin and Robiquet. It may be formed by admitting an equal volume of chlorine to olefiant gas standing over water, in which case the gases diminish in volume, and the oil-like substance collects in globules, and sinks through the liquid; or by transmitting the gases from two separate vessels into a large globular receiver, by which a combination is produced, and the compound subsides to the lower part. To be obtained pure, there must be an excess of olefiant gas, for if the chlorine predominate, it gives to the liquid a tinge of green, which, in order to be removed, requires washing with water, and distillation from muriate of lime.

It is a colourless and transparent fluid, of a pleasant odour and of a sweet, sharp, and not disagreeable taste. Its specific gravity, at the temperature of 44°, according to the French chemists, is 1.2201. The specific gravity of its vapour, according to Gay-Lussac, is 3.4434, and its density at 78°.7 is such, that it will support a column of mercury equal in

* Memoirs of the Wernerian Society, vol. i, p. 550. † Ibid, p. 524.

length to 24.666 inches. From this circumstance it might be inferred *à priori*, that it would boil at a much lower temperature than water. It is in fact actively vaporised at 152° . It burns with a green flame, emits a thick smoke, and deposits a considerable quantity of charcoal.* When agitated in water it dissolves, and the liquid acquires an agreeable taste and odour. It is also dissolved by spirit of wine, ether and nitric acid. It is decomposed by sulphuric acid, and the odour of chlorine becomes perceptible. It evaporates gradually on exposure to the air. Vegetable colours are not altered by it.† According to the analyses of Dr. Thomson and of the French chemists, it appears to consist of 1 proportion of chlorine 33.5, and 2 of olefiant gas $13.4 = 46.9$; or it may be considered as a ternary compound of 1 proportion of chlorine, and 2 proportions each of carbon and hydrogen. When transmitted through a tube of porcelain heated to ignition, it is converted into muriatic acid, and an inflammable gas composed of, or containing carbon and hydrogen, and charcoal is deposited. From the properties exhibited by this substance, it is obvious that it cannot be considered, as was once the opinion of some chemists, analogous to the fixed vegetable oils. It is difficult to find a name adapted to this body upon the principles of the French nomenclature. It was first called by Dr. Thomson *chloride of olefiant gas*, but since M. Gay-Lussac's theory of the constitution of the ethers has been made known, he proposes to change it to *chloric ether*.

CCCCI. The gases which are produced by the different processes already stated (CCCXCIV.) and which are obtained by the distillation of most animal and vegetable substances, differ exceedingly from each other in specific gravity, in the colour and intensity of their flames, and in the quantity of oxygen required for the saturation of their elements. In the following table, the first column is appropriated to the names of the bodies from which the gases are obtained, the second

* Annals of Philosophy, vol. ix. p. 26.

† Dr. Thomson. Memoirs of the Wernerian Society, vol. i. p. 517.

to their specific gravities, and the third to the amount of oxygen required for the combustion of a portion represented by 100 volumes.

Stagnant Water gas	- - -	0.5550	- - -	200
Hydrogen	" - - -	0.0732	- - -	50
Charcoal	" - - -	0.4800	- - -	60
Pitcoal	" - - -	0.5400	- - -	190
Olefiant	" - - -	0.9090	- - -	300

This difference in the weight of combustible matter has been sufficiently proved, by the experiments of Mr. Dalton, Dr. Thomson, Dr. Henry and others, to depend upon the mixture in various proportions of the different gaseous compounds of carbon. Thus the gas from stagnant water contains carburetted hydrogen, carbonic acid, and atmospheric air; pit-coal yields by distillation variable proportions of light and heavy carburetted hydrogen, and carbonic oxide; the products from ignited charcoal are carbonic acid, carbonic oxide, and carburetted hydrogen; and from wood, carburetted hydrogen, and carbonic acid, mixed with simple hydrogen, and gaseous oxide of carbon. From these facts, we may perhaps account for the degree of obscurity which so long hung over the combinations of carbon and hydrogen. Dr. Thomson appears to have demonstrated that there exist but two well defined species of carburetted hydrogen, viz. olefiant gas, and the air from stagnant water when freed from mixture, that they do not contain oxygen, and that they are to be considered as simple binary compounds.*

CCCCII. It has been remarked, that carburetted hydrogen is a production of nature, and that it is copiously evolved in coal mines. This evolution is generally slow and gradual, but it not unfrequently happens, that large quantities are suddenly irrupted into the workings from fissures, which are technically called *blowers*. The gas, which is usually known by

* Memoirs of the Wernerian Society, i. p. 504.

the name of *Fire-damp*, seems in these cases to proceed from a reservoir in which the elasticity is greatly augmented, either by mere accumulation, or by the pressure of a column of water.* This fatal air is generated by the re-action of the elements of the coal, and probably of water; it was found by Sir H. Davy, that when large masses were broken under water, bubbles of gas rose to the surface; and it is so rapidly formed, even after being taken from the mine, that explosions have happened on board the Colliers, while employed in conveying it from Newcastle to London. The extent of many of these mines, their numerous workings, and the depth to which they are explored, render a proper ventilation with atmospheric air almost impracticable. Hence, the use of candles, or of a naked flame, is exceedingly dangerous, the mixture of common air and carburetted hydrogen is in certain proportions inflammable, and as vast quantities are present, the combustion, when it takes place, is rapid and extensive, a terrible explosion is produced, and those of the miners, who are not torn to pieces by the rush of air, or scorched by the flame, are suffocated by the carbonic acid, or choak-damp, as it is familiarly called, which is one of the products of inflammation. In many places, it has been found necessary to substitute for lamps or candles, the steel-mill, consisting of a wheel, the circumference of which is set round with flint, and which, during its revolution, is made to strike against a mass of steel, and throw off red hot sparks. But the light thus produced is feeble, and in many cases inadequate, and the danger of explosion, although diminished, is not removed, for accidents of the kind have been known to happen in mines which were lighted in no other manner.

The fire-damp has been analysed by Dr. Henry, and the results of his experiments were confirmed by the later analysis of Sir H. Davy. It was found to consist of

* Menzies,—Annals of Philosophy, vol. vii. p. 282.

Atmospheric air	-	-	-	63.54
Inflammable gas	-	-	-	35.00
Carbonic acid	-	-	-	1.66
				<hr/>
				100.00

CCCCIII. The frequent occurrence of explosions, and the number of valuable lives annually lost in Great Britain by these accidents, sufficiently showed that the methods of ventilating, and of lighting the mines, were both imperfect, and that it was an object of the first importance, to be able to supply a lamp, which at the same time should afford a sufficient light, and enable the miner to proceed with his labours with confidence in his security. Accordingly, various methods were suggested for this purpose, and much ingenuity has been displayed, to complete this humane object. The *Steam safety-lamp* of Dr. Reid Clanny is founded upon the principle, that fire-damp, mixed in certain proportions with the steam of water, is incapable of exploding when brought into contact with flame; in carrying this principle into execution, an instrument of a neat and simple form was employed, and experiments which were made with it in mines abounding with the inflammable air, demonstrated that it was adequate to the purpose for which it was invented.* A lamp constructed upon a different principle, by Dr. Murray of Edinburgh, has also been practically applied, and found to answer the same end. It seems to have been proved, that the fire-damp, in consequence of its specific levity, accumulates in the upper part of the mine, and the method proposed by Dr. Murray to prevent the gas from coming into contact with the flame, was to bring the supply of air to sustain the combustion of the oil from the floor. This was easily effected by burning the lamp within a glass-case, having a small aperture at the top to admit of the escape of the smoke and heated air, and having attached to the under part of it a tube, reaching to the floor

* Annals of Philosophy, vol. viii. p. 354.

of the mine to convey the air.* But these useful and ingenious contrivances appear to have been rendered unnecessary, by the simple and beautiful invention of Sir Humphry Davy.

CCCCIV. It was ascertained by this great chemist, that explosions of inflammable mixtures were incapable of being passed through long narrow metallic tubes, and that the same obstruction was experienced, as they were diminished in length and diameter, or diminished in length and increased in number, so that a great number of apertures would not pass explosion, when their depth was equal to their diameter. Proceeding upon this principle, the security against explosion was shown to be the same when, instead of tubes, a number of fine wires were so arranged as that the spaces between them should be very small. Hence, when the flame of a lamp was surrounded on all sides by a wire sieve, the meshes of which amounted to 250 in a square inch, it might be introduced into a gaseous explosive mixture, and cause the portion within to burn, without communicating the flame to that with which the external surface was in contact. Hence, a lamp constructed upon this principle, might be used with safety in coal mines, in which fire-damp is collected, and in which a naked flame would cause an immediate explosion. This instrument consists of two parts, a lamp of common construction, and a cylinder of wire-gauze. The lamp is about 2 inches in diameter, provided with a wick in the usual form, with an aperture on the outside to introduce the oil, and a wire passing through a safety tube for raising, lowering, or trimming the wick. This lamp when lighted is fastened to the cylinder of wire-gauze by a screw of four or five turns in a strong brass ring. The cylinder, which is about 2 inches in diameter, and from 7 to 8 inches in height, is now formed of thick twilled iron-gauze, which contains 16 wires in warp and about 30 in weft, and where connected at the top and the bottom, it is folded over in such a way as that no aperture

* Observations on the Fire-damp of coal mines, &c. from the Transactions of the Royal Society of Edinburgh. 1816.

shall be left in the apparatus larger than in the wire-gauze. A second top is also attached to it, about $\frac{1}{2}$ or $\frac{3}{4}$ of an inch from the sieve, and it is supported firmly in its place by 3 thick iron wires rivetted into the brass ring at the bottom. To this top is fixed an iron ring, for the purpose of suspending the lamp. Sir H. Davy has found that a glass cylinder placed within the gauze causes the lamp to burn with greater brilliancy; and Mr. Newman has rendered it capable of affording a concentrated light, by fixing to the outside a convex lens. It is obvious from this construction, that as the air within becomes rarefied, the gauze-wire will offer but a slight resistance to the passage of the warm air through the upper part, and of the fresh air through the sides of the cylinder, and, presuming upon the correctness of the principle upon which it is constructed, that it will not afford so great an obstruction to the passage of the light, as to prevent it from answering to the miner all the purposes of a naked flame, while it places him in a state of confidence and security.

When this lamp is lighted and introduced into an atmosphere gradually mixed with fire-damp, the first effect is to increase the length and diameter of the flame; if the inflammable gas form as much as $\frac{1}{12}$ of the volume of the air, the cylinder becomes filled with a feeble blue flame, but the wick appears burning brightly within the blue flame, till the fire-damp increases to $\frac{1}{6}$ or $\frac{1}{5}$, when it is lost in the flame of the fire-damp, which in this case fills the cylinder with a pretty strong light. After a while, when the foul air, produced by the combustion, amounts to about $\frac{1}{3}$ of the volume of the atmosphere, the light becomes extinguished.

When the lamp is introduced into a more explosive mixture, the cylinder is filled with a blue flame, a singing noise is heard, and the flame is destroyed. In all these cases, though the inflammable gas within the cylinder burns, yet the combustion is not communicated to the explosive mixture by which it is surrounded. It was found by Sir H. Davy, that when the cylinder was formed of wire $\frac{1}{50}$ of an inch in diameter,

and contained 10 wires to the inch, the combustion was not extended beyond it, but if the lamp were agitated, the flame was communicated to the mixture in contact. When there were 14 wires to the inch, the flame was not propagated by agitation, and with 24 wires, the air did not explode even when the wires were red hot. The fact is, that an explosive mixture requires a high heat for its combustion, and to produce this effect, a red hot wire of considerable size is necessary.

The theory of the operation of the safety-lamp in preventing explosions is founded, partly upon the quantity of heat necessary to the combustion, and in part upon the cooling agency of the wires of which the sieve is formed. When combustion takes place within the cylinder, the flame comes into contact with the wires, and a portion of heated air is pressed through the apertures, but in consequence of the high conducting power of the metallic gauze, this air in its passage communicates so much of its heat, that by the time it is on the outside, its temperature is reduced below that required for explosion, and it is rendered incapable of communicating flame to the mixture. The wires themselves though red hot cannot produce this effect; the red heat takes place only at the top, and there in consequence of their small size, and the circumstance that the gas without is mixed with the carbonic acid and azote proceeding from within the cylinder, the mixture is rendered unexplosive. Sir H. Davy has shown that when the inflammable mixture contains $\frac{1}{3}$ of its volume of azote or carbonic acid its power of exploding ceases.

These lamps have been tried in mines which had been abandoned in consequence of the quantity of fire-damp accumulated in them, and have been daily used for months in others in which precautions were required to prevent explosions; and the experiments have perfectly succeeded. No instance has yet been known of any accident of the kind having happened in those cases in which the mines have been lighted by the safety-lamp, and the author must enjoy the

pure and sublime pleasure of having preserved hundreds of men from death, and their families from despair, by the direct application of the principles derived from his own science, to one of the pursuits most essential to the prosperity of his country.

CCCCV. The different species of carburetted hydrogen, it is now well known, have been applied with success, under the name of *Gas-light*, to the purposes of illumination. Their powers in this respect were ascertained so long ago as 1739 by Dr. Clayton, who, in a letter to Mr. Boyle, gives an amusing account of his attempts to obtain the gas, and the experiments performed with it.* It does not appear that the light afforded by gas was economically applied as a substitute for that of oil, tallow or wax, until between the years 1790 and 1800.† The merit of having demonstrated its practicability is due principally to Mr. Murdock, but some credit is also to be given to Mr. Windsor, and to M. Le Bon, the last of whom first exhibited the gas-lights at Paris.

Gas for illumination is obtained in large quantity from pit-coal, particularly that species which abounds most in bitumen, and it is produced by distillation. The apparatus employed consists of several parts, in which the gas is successively produced, freed from the vapours with which it is mixed, and from the disagreeable odour which it exhales when first formed, and collected for use. The coal is distilled in iron retorts in an appropriate furnace, and the gas, with other volatile products, passes from them into a tube which leads through the water in a reservoir, into a vessel placed near it, and intended to receive the tar and ammoniacal liquid condensed in the tube; from this vessel the gas proceeds into another, where it comes into contact with slaked lime and water, by which it is freed from carbonic acid, and sulphuretted hydrogen. When this is accomplished, the purified gas

* Philosophical Transactions for 1739.

† Mr. Brande. Journal of Science and the arts, vol. i. p. 71. Accum's Practical Treatise on Gas-Light, p. 57.

is conducted by a pipe into a gazometer, and disposed of in such a manner, as that it shall be exposed to a large surface of water before it rises into the receiver, which is formed of sheet iron, and suspended by weights. From this it is propelled to the points where it is to be inflamed by the weight of the receiver itself.*

A considerable quantity of tar during this operation distils over, and it is used for a variety of purposes. One chaldron of Newcastle coal produces from 150 to 180 pounds of this substance, but it requires to be evaporated to a certain degree before it can be employed in the arts. When this concentration is conducted in close vessels, a brown ammoniacal liquor first separates, and then there rises a yellowish inferior kind of oil of turpentine, 53 pounds of which are obtained from 200 pounds of tar. The watery liquid holds in solution sulphate and carbonate of ammonia, and is employed in the manufacture of sal ammoniac. The residuum in the retorts, after the distillation, is valuable as a substance capable when ignited of producing an intense heat without flame. It is called *coak*, and appears to bear the same relation to coal, as charcoal bears to wood.

A chaldron of good Newcastle coal will afford, according to Mr. Brande, from 17000 to 20000 cubical feet of gas, but as distilled in the large way it seldom gives a larger average produce than 12000 square feet.† At the three stations belonging to the Gas-light Company in London, there were daily carbonised, at the period of Mr. Brande's communication, 25 chaldrons of coal, which actually yielded 300000 cubical feet of gas, equal to the supply of 75000 Argand's lamps, each lamp giving the light of six wax candles. At the City Gas-works the consumption of coals for distillation amounted to three chaldrons a day, and the gas produced afforded a supply for 1500 lamps, so that the total consump-

* The minutiae of this operation may be found in Accum's Practical Treatise on Gas-light.

† Journal of Science and the Arts, vol. i. p. 71.

tion of coals daily in London for the purpose of illumination was equal to 28 chaldrons, and the number of lights supplied to 76000. The tubes which convey the gas from the gazometers have been estimated to amount in length to more than 60 miles; the burners or tubes, whence the gas issues and is inflamed, may be infinitely varied, and Mr. Accum in his Treatise has delineated a number of tasteful and elegant lamps. The varieties commonly employed, according to Mr. Brande, are the bat's-wing burner, and the Argand burner. The former consists of a brass tube having a slit at its extremity about a quarter of an inch in length, and $\frac{1}{30}$ of an inch wide. The latter is composed of two concentric brass tubes about two inches in length, closed at bottom by a ring of brass, and at top by one of steel perforated with 16 or 18 holes of $\frac{1}{30}$ of an inch in diameter. The gas enters the cavity between the tubes, and issues from the circular row of apertures, where it is inflamed, and having a due supply of air within and without, burns very beautifully when a proper glass is placed over the burner. These burners, when very carefully regulated, consume about 3 cubical feet of gas per hour, and give light equal to 6 wax candles. The pipes leading to the burners are furnished with stop-cocks.

CCCCVI. The expense of lighting large establishments in this way has been compared by Mr. Murdock with that of illuminating by candles. At the extensive cotton mills of Mess. Phillips and Lee of Manchester, nearly a thousand burners of different forms were employed, the light of which was estimated to be equal to that of 2500 well managed candles of six to the pound. The cost of 110 tons of coal annually used to furnish the gas was 125*l.*; of common coal to carbonise or distil it 20*l.*; and the interest of the capital employed in the apparatus 550*l.*; from which is to be deducted the value of the coak, amounting to 93*l.*, and then the whole expense of lighting the establishment was reduced to 602*l.* while the expense of candles to give the same light was estimated at not less than 2000*l.* The peculiar softness and clearness

of the light, says Mr. Murdock, with its almost unvarying intensity, brought it into great favour with the work people; and its being free from the inconvenience of sparks, and the frequent necessity of snuffing, are circumstances of material importance in cotton-mills, which are so apt to be sacrificed by carelessness or imprudence.

CCCCVII. The gas which is produced during the distillation of coal is a mixture of different species of inflammable matter; 100 parts were found by Mr. Brande to consist of

8	Olefiant gas
72	Carburetted hydrogen
13	Carbonic oxide and hydrogen
6	Carbonic acid
1	Sulphuretted hydrogen

100

Two of these gases, the carbonic acid and the sulphuretted hydrogen, are abstracted principally by the lime-water through which the mixed gases are transmitted previous to their entering into the receiver. The density and brightness of the flame depend upon the olefiant gas, and the light has been inferred to be about $\frac{1}{3}$ greater than that produced by the flame of a candle of the same size, and kept burning in the best possible manner. Accordingly, it has been found that the quantity of oxygen consumed in a given time by the elements of tallow or wax is much less than that absorbed by the gases.

The greatest obstacle to the general introduction of the gas-lights, as a substitute for the usual modes of illumination, has been the disagreeable odour which they exhale; but this difficulty, if not entirely removed, is so far lessened, that little inconvenience is now experienced. The removal of the substances, to the presence of which this quality is owing, depends entirely upon the degree of washing to which the elastic fluids are exposed. Hence it has been found necessary not only to bring them into extensive contact with water, but likewise to transmit them through milk of lime. When properly purifi-

ed, they have a decided advantage over the light procured by the combustion of oil, tallow, and wax. The light which they afford is more brilliant and equable, they produce nothing but carbonic acid and water, and are incapable of soiling the whitest garment, or the most polished furniture; the combustion of the substances above mentioned, on the contrary, is often accompanied with smoke of a disagreeable empyreumatic odour, and the vapour which rises is soon condensed into a light charcoal, that leaves a trace upon the articles upon which it rests.

Carbon is capable of uniting with azote, and of forming an interesting compound, which constitutes the radical of the prussic acid, and which M. Gay-Lussac has designated by the name of *Cyanogen*. The consideration of the properties of this substance, and of its combinations, we shall leave for a separate section.

When concentrated nitrous acid is added to perfectly dry and warm charcoal, a violent action takes place, and it sometimes happens, that the latter takes fire and burns with flame. The acid in this case is partially decomposed, nitric oxide and sometimes nitrogen gases are disengaged, and carbonic acid formed.

SECTION VI.

Of Phosphorus.

CCCCVIII. This curious and highly interesting compound was discovered in 1669, by Brandt, an alchemist of Hamburgh, while engaged in the extraordinary experiment of attempting to extract from urine the philosopher's stone, or a substance capable of converting the less valuable metals into gold. A few years after, Kunckel, who knew only that it was formed from the liquid above mentioned, succeeded in obtaining it; and the process was also discovered by Boyle, who imparted the secret to a London apothecary, and by him it was manufactured in such quantities, as to supply all Europe; hence, it was for some time known by the name of English phosphorus. The properties of this element, and of the compounds which it forms with other bodies, became successively the subjects of examination, from the period of its discovery, until the present time, but such have been the difficulties in their investigation, that, notwithstanding the researches of Davy, Gay-Lussac and Thenard, Vogel, Dulong, Berzelius, Thomson and Dalton, the number of its compounds with some of the other elementary bodies, or the proportions in which they unite, cannot yet be considered as firmly established.

From the mode in which it was first obtained, it must have been sold excessively high, but since the discovery of Gahn, that the phosphoric acid exists in the bones of animals, and the process of procuring it from them by Scheele, the method of extracting it has been rendered not only less offensive, but likewise more productive. The bones of carnivorous animals, it is said, yield the largest quantity of this acid.

CCCCIX. The greater portion of osseous matter consists of phosphoric acid combined with lime, and in order to obtain phosphorus, the first step of the process consists in decompos-

ing this phosphate and disengaging the acid. For this purpose, 100 parts of bones, which have been previously calcined, or exposed to heat until all their animal matter has been dissipated, are reduced to fine powder, and mixed in a vessel of ware with 4 or 5 times their weight of water; to the mixture are gradually added, with frequent agitation, 40 parts by weight of sulphuric acid, heat is produced, and a quantity of air-bubbles disengaged, and the whole is allowed to remain for 24 hours, the mass being frequently stirred with a glass rod. By this operation, the phosphate of lime contained in the bone is decomposed, the sulphuric acid combines with the base, the phosphoric acid is separated, and remains dissolved in the liquid. The whole is then filtered through cloth, and to the clear acid liquor is to be added, by small portions at a time, an aqueous solution of the salt, called nitrate of lead, until a precipitate ceases to be formed. The white substance thus separated is a compound of the phosphoric acid with the oxide of lead, for when the two liquids come into contact, the nitrate of lead is decomposed, its base or the oxide unites with the phosphoric acid and forms an insoluble phosphate of lead. The next step of the process is to decompose the phosphoric acid, and it is done by filtering the liquid mass, collecting and drying the white and solid salt of lead, mixing it with $\frac{1}{2}$ or $\frac{1}{3}$ its weight of charcoal powder, and putting the whole into a stone-ware retort, the body of which has been previously coated with a mixture of sand and clay. It is then deposited in a furnace, its mouth is immersed in cold water, and the heat is gradually raised to whiteness. After the emission of a great quantity of air-bubbles, some of which take fire spontaneously on coming into contact with the atmosphere, there drops from the mouth of the retort a substance resembling melted wax, which is soon converted under the surface of the water into a solid. In this experiment, the affinity of the charcoal for oxygen, aided by an intense temperature, causes the decomposition both of the phosphoric acid, and the oxide of lead with which it is combined, their oxygen is transferred

to the charcoal, which passes off in the form of carbonic acid gas, while the phosphorus, thus reduced to its simple state, rises, in consequence of the high heat, in the state of vapour, becomes condensed in the neck of the retort, and flows in a liquid state into the vessel beneath. If we may judge from the products of the distillation, a quantity of water is also decomposed. Some caution is required to conduct this operation with safety. The phosphorus is apt to harden at the mouth of the retort, and unless it be removed the passage will be closed, and the elasticity of the gases which are disengaged will burst the vessel with an explosion. To prevent this occurrence, the mouth of the retort should be wide, or the phosphorus should be occasionally removed by applying heat to the neck, or by introducing into it an instrument which shall detach it from the internal surface. The phosphorus after the first distillation is mixed with charcoal, and nearly black, hence it is necessary to purify it, and it may be done by melting it under the surface of water, and in that state pressing it through chamois leather; by allowing it to remain for a few minutes in contact with nitric acid; or by distilling it in a retort filled with hydrogen gas, the beak being immersed under the surface of cold water. The last process is said to yield it in a state of greatest purity. When thus freed from charcoal, it is again melted in hot water, it is drawn into a glass tube where it concretes, and when removed, appears in the shape of a cylinder, which requires to be kept in a vessel filled with water.

CCCCX. Phosphorus thus prepared is of a reddish yellow colour, but when very pure nearly colourless, of a radiated or striated texture, insipid, and of a hardness equal to that of wax, but more ductile. It is translucent at the edges and flexible. Its specific gravity is 1.77. When exposed to the temperature of 99° , or according to Dr. Thomson 108° , it becomes liquid, evaporates when excluded from the air at 219° , and is actively vaporized at 554° . Thenard affirms, that when heated to 140° , and suddenly cooled, it becomes

black. According to Pelletier, it is capable of crystallizing in needles or in octoedra from its solution in spirit of wine or an essential oil ; and when melted under the surface of water and cooled until a crust is formed upon it, if the crust be pierced and the liquid phosphorus be allowed to flow off, the internal surface of the cavity will be found covered with crystals similar to those produced by sulphur, when the same process is employed.

From the experiments of Orfila, it appears to be an active poison when taken into the stomach. Leroi has stated some singular effects produced by it upon animals.*

CCCCXI. When in contact with atmospheric air at common temperatures, it emits a white smoke which is luminous in the dark, and indeed in such situations the whole mass when dry shines with a mild light, having a faint tint of green. These white vapours possess a peculiar odour, which has been compared by many with that of garlic ; they are the product of the combination of phosphorus with oxygen. The disposition to unite with that element slowly, and without the phenomena of active combustion, has given rise to many curious experiments. Traces made by it upon different bodies shine vividly in the dark, and the same effect is produced by some of its solutions ; for if a few grains of it be put into a phial partly filled with olive oil, they may be dissolved by the application of heat, and if after the vessel has been shaken, the stopper be withdrawn, the whole space above the liquid will become so luminous as to allow the hour on a watch to be distinguished. But to produce this effect, it is requisite that the solution should have been recently prepared, or at least heated. A solution of phosphorus in spirit of wine may be formed by the same method, and when a few drops of the liquid are poured upon water in the dark, a mild and beautiful phosphoric light will be observed to play in successive undulations over its surface. One species of *phosphoric bottle* is prepared by melting 2 or 3 grains of this substance in a

* Nicholson's Journal, vol. iii. p. 85.

small glass or leaden phial, stirring it with an iron wire so that it may adhere to the whole internal surface, and excluding it from the air. A match tipped with sulphur, when introduced into it and moved briskly, will generally take fire on being withdrawn.

Great difficulty has been experienced in determining the proportions in which phosphorus combines with oxygen; there are several compounds known of the two elements, and those, the existence of which appears to have been most clearly demonstrated, are 1. Hypo-phosphorous acid. 2. Phosphorous acid. 3. Phosphoric acid.

1. *Hypo-phosphorous acid.*

CCCCXII. This compound was discovered in 1816, by M. Dulong. When an alkaline phosphuret, a compound formed by the union of phosphorus and lime, barytes, or strontian, is immersed in water, the liquid is decomposed, hydrogen gas holding phosphorus in solution is disengaged, while the oxygen combines with the remaining phosphorus, and forms two acids, the phosphoric and hypo-phosphorous acids; these substances, immediately after their formation, unite with the base of the phosphuret, and produce two salts. In the case of phosphuret of barytes, it was found that the two salts were phosphate and hypo-phosphite of barytes, the former being insoluble, while the latter was very soluble in water. They were therefore readily separated by filtration, and by the addition of sulphuric acid to the solution, the barytes was precipitated in the form of sulphate, the hypo-phosphorous acid remaining uncombined in the liquid. It has the following properties. When concentrated by evaporation, it appears in the form of a viscid liquid, possessing a sour taste and the property of reddening vegetable blues. It is incapable of assuming a crystallized state. Exposed to heat after having been concentrated, this acid gives out phosphuretted hydrogen gas, a

small portion of phosphorus sublimes, and pure phosphoric acid remains. It combines with the salifiable bases and forms neutral salts called *hypo-phosphites*, which are very soluble in water, and some of them, as those of potash, soda, and ammonia, in alcohol or spirit of wine. The salts which have barytes and strontian for their bases crystallize with difficulty from their solutions. According to the experiments of M. Dulong, it is composed by weight of 100 parts of phosphorus, and 37.44 of oxygen; Sir H. Davy considers it as a compound of 1 proportion each of phosphorus and oxygen, and in adopting this opinion, the number for phosphorus upon the principles of this work, may be readily found; for $37.44 : 100 :: 7.5 : 20.03$; and the hydro-phosphorous acid will consist of 1 proportion of phosphorous 20, and 1 of oxygen 7.5, or 27.5. Dr. Thomson conjectures that the snow-white substance which sublimes when phosphorus is exposed to heat in a narrow glass tube, and which burns spontaneously on coming into contact with the air, is hypo-phosphorous acid.*

2. Phosphorous acid.

CCCCXII. This acid was formerly obtained by exposing phosphorus to the air in a glass funnel, which opened into a receiver containing a small quantity of water. In this state, it experienced what has been termed a slow combustion, it combined with oxygen, and the white fumes which were formed, being heavier than the air, sunk into the receiver, and were condensed by the liquid. But it was ascertained by Sir H. Davy, that the body thus produced was a mixture of phosphorous and phosphoric acids, and that the best method of procuring the former in a state of purity was to sublime phosphorus through corrosive sublimate or the per-chloride of mercury. The salt is put into a glass tube, connected at one end with a small receiver, kept cool, and at the other with a small tube containing phosphorus, heat is applied to the latter.

* System of Chemistry, vol. ii. p. 103. 5th ed.

the combustible rises in vapour, comes into contact with the corrosive sublimate, decomposes it by combining with its chlorine, and passes into the receiver in the form of a transparent liquid. This chloride of phosphorus when poured into water decomposes it, phosphorous and muriatic acids are formed, and the latter is evolved by evaporating the solution to the consistence of a syrup.* On cooling, it forms a white crystalline solid, which reddens vegetable blues, combines with the alkalies, and has all the characters of a strong acid. On exposure to the air, it absorbs oxygen and is converted into phosphoric acid. When heated, it takes fire, burns with great brilliancy, emitting globules of gas which inflame in contact with the air, and leaves a red substance which has been considered as an oxide of phosphorus. The phosphorous acid combines with the salifiable bases, and forms salts which have received the name of *phosphites*.

Phosphite of ammonia is in the form of delicate, prismatic or acicular crystals, which, when exposed to heat before the blowpipe, are decomposed, increase in bulk, and produce phosphuretted hydrogen gas.

The composition of this compound was ascertained by the quantity of muriatic acid formed, for the proportion of hydrogen contained in this acid being well known, it was easy to calculate the amount of oxygen required to convert phosphorus into phosphorous acid. It was found that 10 grains of this substance required 7.7 grains of oxygen to form the acid, and that the quantity of phosphorus being the same, twice as much oxygen was necessary to form phosphoric acid, as was required for phosphorous acid; hence the latter was considered as a compound of 1 proportion each of the two elements. But from more recent experiments, the proportions by weight in this acid have been estimated at 100 parts of phosphorus, and 67.25 of oxygen. Considerable difference, therefore, exists upon this point, for the quantity of oxygen combined with 100 of phosphorus in phosphorous

* Elements of Chemical Philosophy, Part i, p. 163. Amer. ed.

acid, has been stated by Thenard as high as 110, by Gay-Lussac at 76, and by Dulong at 78.88. Upon the supposition that this acid contains two proportions of oxygen, as is very probable, it may be represented by $20 + 15$, or 35, and its composition may be stated as follows.

		Prop.			Atoms.			Weight.
Phosphorus	-	1	-	-	1	-	-	57.15
Oxygen	-	2	-	-	2	-	-	42.85
		<hr/>			<hr/>			<hr/>
		3			3			100.00

It is obvious that the phosphorous acid exists in this compound as an hydrate, hence it has been called by Sir H. Davy, *hydro-phosphorous acid*; for when heated over mercury in contact with ammonia, the latter combines with the pure acid in the former, and water is expelled: and the proportions are stated by this distinguished chemist to be 2 of water to 4 of the acid. Considering it as containing 1 proportion of water, the hydrate may be represented by $35 + 8.5$, or 43.5.

3. *Phosphoric acid.*

CCCCXIII. This acid is the result of the full oxygenization of phosphorus, and is the most important of all the compounds of this element. When phosphorus is kindled in oxygen gas, it burns with great vehemence, gives out an intensely brilliant light, and fills the vessel with dense white fumes, which, if the materials have been previously dried, soon condense into a white crystalline solid. This is phosphoric acid, but the method of procuring it in this way is too expensive, and the quantity obtained is too small to be generally employed. The common process to form this acid consists in mixing nitric acid with the liquid which is produced by the long exposure of phosphorus to atmospheric air, in the way already mentioned, with a quantity of nitric acid, exposing the

mixture for some time to a moderate heat, and afterwards evaporating to dryness in order to drive off the remaining nitric acid. The object in this process is to communicate oxygen to the phosphorous acid in order to convert it into phosphoric acid, and the oxygen is obtained by the decomposition of the nitric acid. The same compound may be formed by dissolving phosphorus in nitric acid, or more readily by adding to hydrophosphorous acid $\frac{1}{8}$ of its weight of nitric acid of the specific gravity of 1.3, and applying a moderate heat, phosphoric acid is produced, and the liquid should then be evaporated in a basin of silver or platina.

CCCCXIV. Phosphoric acid is in the form of a vitreous transparent solid, destitute of odour, but possessing an exceedingly acid taste. When exposed to the air it attracts its aqueous vapour, and changes to a dense oil-like liquid. By the action of heat the solid acid first loses its water and then remains in a liquid state, incapable of change, until the temperature is raised nearly to whiteness, when it is partly volatilized. When cooled it has the appearance of glass, and hence it has been long known by the name of *Glacial phosphoric acid*. Its specific gravity, according to Hassenfratz, is then 2.8516.

CCCCXV. It is not a little remarkable that notwithstanding the apparent simplicity of the principal experiment by which it has been attempted to discover the proportions of the elements in phosphoric acid, viz. the combustion of phosphorus in oxygen gas, so great a difference should be found to exist in the estimates of different chemists. The composition of this acid has been made the subject of experiment by Lavoisier, Rose, Thomson, Davy, Dulong, and Berzelius, yet they have all stated the amount of oxygen differently, the quantity varying from 114 parts to 163.40 of oxygen combined with 100 of phosphorus. Sir H. Davy in his late experiments fixes the proportions at 100 of phosphorus to 134.5 of oxygen; the mean of the experiments of the chemists above mentioned gives $100 + 133.43$; we may therefore

take 134.5 as the quantity of oxygen in 234.5 of phosphoric acid, and as it has been found to contain twice as much oxygen as exists in phosphorous acid, it will consist of 1 proportion of phosphorus 20, and 4 proportions of oxygen 80, and it may be represented by 50.

Phosphoric acid even after having been exposed to a red heat contains water, and the quantity has been estimated by M. Dulong at 20.6 parts for 100 of dry acid. It is therefore in the state of hydrate.

When slightly moistened and exposed to voltaic electricity in a state of intensity, it is decomposed, and phosphorus is disengaged at the negative, and oxygen at the positive pole. As obtained by the combustion of phosphorus in dry oxygen, it is very soluble in water, and the solution is attended by a hissing noise and an increase of temperature, but it is less soluble, or at least requires a much longer time to dissolve, when in the form of glass. The concentrated solution acts upon and corrodes vessels of glass and of pottery ware, hence when required in a pure state the articles employed for converting it into the glacial acid should be metallic. Phosphoric acid combines with the salifiable bases and forms salts, which are called *Phosphates*; the affinities which unite the two constituents of these compounds are in general very powerful, and few acids are capable of decomposing them.

Phosphate of ammonia exists in the urine of carnivorous animals, and when combined with the substance commonly called soda, it forms the microcosmic or fusible salt of urine of the earlier chemists. The pure phosphate of ammonia may be formed by the direct combination of its constituents. It crystallizes in small 4 sided prisms, acuminate by 4 planes, and the crystals are neither efflorescent nor deliquescent. On exposure to heat it melts into a glass, and is afterwards decomposed, a part of its ammonia being expelled. It is also at a high temperature decomposed by charcoal, the phosphorus losing its oxygen; and it was from this salt, or rather the triple compound of this acid, ammonia, and soda, that phosphorus was first obtained.

CCCCXVI. M. Dulong has described a compound of phosphorus and oxygen by the name of *Phosphatic acid*, which is formed by the exposure of phosphorus to moist air with the same precautions as those which were formerly taken in the preparation of phosphorous acid. He states the proportions at 100 of phosphorus to 110.39 of oxygen ; but it is somewhat doubtful whether the liquid resulting from this process can be considered as a distinct acid. Sir H. Davy, in examining phosphorous acid prepared in this way, found it to be a mixture of this compound with phosphoric acid ; and a fact mentioned by M. Dulong himself would seem to favour, if not confirm this conclusion, that in combining with the salifiable bases it is converted into these two acids, and it is therefore possible that the phosphatic acid may be merely a mixture. The late experiment of Sir H. Davy have likewise rendered the existence of this acid very doubtful.

CCCCXVII. Phosphorus is insoluble in water, but after it has remained for some time immersed in it, the surface becomes covered with a white crust, which turns to a brown colour when exposed to light. This pellicle has been examined, and been thought to be an oxide of phosphorus. This name however has been given to a substance of a very different appearance. When phosphorus is consumed in atmospheric air, particularly when rarefied, there remains a reddish coloured substance, which by gentle friction, and sometimes even by exposure to the atmosphere, takes fire and burns with the splendour of pure phosphorus. This has been conceived by Sir H. Davy and other chemists to be likewise an oxide, so that we shall have two oxides, for the characters of the substances are so dissimilar that it is not probable both should contain the same proportion of oxygen. The red matter has been supposed to be a compound of 1 proportion of oxygen with 2 proportions of phosphorus. Experiments, however, are still wanting to decide upon the real nature of the bodies just mentioned.

Chlorides of Phosphorus.

CCCCXVIII. When phosphorus is introduced into chlorine gas, which has been caught over water, a white vapour is first observed to rise from it, the mass then takes fire, burns with a pale whitish flame, occasionally throwing out sparks, the vapours increase in quantity, and after the combustion has ceased, these fumes will be found condensed into a transparent liquid; but if chlorine be introduced into a receiver exhausted of air and containing phosphorus, combustion takes place, and a white substance rises, which soon after condenses in a solid form upon the sides of the vessel. If the elements be in the proportion of 12 cubic inches of the gas to 1 grain of the phosphorus, the latter entirely disappears, or is converted into the white substance. This is the *Perchloride* of phosphorus, its properties were first examined in 1810, by Sir H. Davy, and they are curious and interesting.

CCCCXIX. It is a snow white substance, very volatile, and capable of being volatilized at a temperature inferior to that of boiling water; under pressure it may be melted, and on cooling it crystallizes in prisms which are transparent. When it comes into contact with water, the liquid is decomposed with violence, oxygen is transferred to the phosphorus and hydrogen to the chlorine, and the results are phosphoric and muriatic acids. When exposed to the flame of a taper, it takes fire; and transmitted mixed with oxygen through a glass tube heated to redness, it is decomposed, phosphoric acid is formed, and chlorine disengaged. It has acid properties, for when dry litmus paper is exposed to its action in a vessel exhausted of air, it is changed to a red. Perchloride of phosphorus combines with ammonia when it is introduced into a vessel containing it, with much heat, and they form together a compound insoluble in water, indecomposable by acid or alkaline solutions, and having characters analogous to an earth.* According to Sir H. Davy, it is composed by weight

* Phil. Trans. for 1812, p. 406.

of 1 of phosphorus and 6.8 of chlorine ; and the proportions, therefore, are 2 of chlorine 67, and 1 of phosphorus 20, so that it may be represented by 87.

CCCCXX. It has been remarked, that when the vapour of phosphorus is transmitted over the surface of a chloride of mercury, a peculiar liquid is obtained. M. M. Gay-Lussac and Thenard prepared this compound by putting into a tube closed at one end, about an ounce of phosphorus, and over it 4 or 5 ounces of calomel, (*mercure doux*,) a small tube was fastened to the mouth and made to open into a receiver. Heat was first applied to the calomel, and when the temperature was raised above 300°, the phosphorus was heated until it passed in vapour over the mercurial compound. The chlorine combined with the phosphorus, and a quantity of metallic mercury remained.* Sir H. Davy made use of corrosive sublimate instead of calomel, and it is preferable, as it contains double the proportion of chlorine. The compound obtained by this process is the *Proto-chloride* of phosphorus, and the nature of it was first ascertained by Sir H. Davy.

It is a colourless and transparent liquid, acid, very caustic and fuming. When paper moistened with it is exposed to the air, it takes fire and burns with the characters of phosphorus.† When inclosed in a vessel, it is not altered by time, but if in contact with the atmosphere, it is decomposed in a few days, and deposits a large proportion of phosphorus. It has no effect, according to Sir H. Davy, on dry vegetable colours, nor does it inflame on paper, results which do not agree with those of the French chemists.‡ It emits acid fumes when exposed to the air, because it decomposes its aqueous vapour, and forms muriatic and phosphoric acids; when introduced into a vessel containing chlorine, it combines with an additional proportion, and is converted into the perchloride; if made to act upon ammonia, phosphorus is deposited, and the same compound as that formed by ammonia, and the per-

* *Rechères Physico-Chimiques*, t. ii. pp. 98—176.

† *Ibid.*

‡ *Elements*, p. 166. Amer. ed.

chloride is produced. The action of water upon this liquid has been already detailed.

When the liquid after the addition of water is evaporated to a certain degree, it becomes thick and viscid, and on cooling crystallizes in the form of transparent parelloipedons. The distillation of these crystals in a close vessel produces a gas which is a compound of phosphorus and hydrogen, and phosphoric acid remains. They are composed, according to Davy, of 4 proportions of phosphorous acid, and 1 proportion of water.

When phosphorus is gently heated in the proto-chloride, a portion of it dissolves, and the fluid when exposed to the air gives off acid fumes, from its action upon the aqueous vapour, and a thin film of phosphorus remains, which usually inflames by the heat generated from the decomposition of the vapour.*

The proto-chloride is a compound of 1 proportion each of phosphorus and chlorine. These compounds have been designated by Sir H. Davy by the names of Phosphorana and Phosphorane, but they do not appear to have been adopted by chemists in general.

Iodides of Phosphorus.

CCCCXXI. When 1 part of phosphorus and 8 of iodine are mingled with each other in a thin glass tube, they combine, according to Gay-Lussac, with great rapidity, produce heat but not light, and form a compound of a reddish brown colour.† Dr. Thomson affirms, that the proportion of iodine is too small, and that it should amount to 10.41 parts.‡ This compound is fusible at 212°, and volatile at a higher temperature. When brought into contact with water, the liquid is decomposed, phosphuretted hydrogen gas is formed, flocks of

* Sir Humphry Davy.

† Memoir on Iodine.—Translated.—Annals of Philos. vol. v. p. 103.

‡ System of Chemistry, vol. i. p. 270. 5th ed.

phosphorus are precipitated, and the water which is colourless contains in solution phosphoric and hydriodic acids.

One part of phosphorus to 16 of iodine produces a matter of a greyish black colour, crystallizable, and fusible at 84° .

If the proportion of iodine amount to 24 parts to 1 of phosphorus, a black substance is formed, which is partly fusible at 115° , and soluble in water, producing a strong heat; and the solution has a very deep brown colour. If these proportions be correct, three compounds of iodine and phosphorus may be formed, in which the ratio of the iodine to 1 of phosphorus is as 1, 2, 3. Dr. Thomson, however, is of the opinion that there are but 2 iodides of phosphorus, the first, or protiodide, being composed of 1 of phosphorus and 10.41 of iodine by weight, and the periodide of 1 phosphorus + 20.82 iodine.* To these compounds, M. Gay-Lussac has given the name of *iodurets*; but the term *iodides* is more conformable with the principles of the present nomenclature.

Phosphuretted hydrogen.

CCCCXXII. Hydrogen possesses the property of dissolving phosphorus, and of forming with it a curious and interesting compound. This combination was first formed by M. Gengembre in 1783, and a short time afterwards by Mr. Kirwan. Phosphuretted hydrogen, for this is the name which has been applied to the compound, may be obtained, 1. by boiling phosphorus in a retort connected with a pneumatic trough, with a strong solution of potash; 2. by pouring concentrated sulphuric acid into a mixture of phosphorus, zinc filings, and water; 3. by immersing *phosphuret of lime* in diluted muriatic acid. For the purposes of exhibition, the gas may be obtained in a sufficiently pure state by the first method. From one to two drachms of phosphorus cut into small pieces are to be introduced into a plain and strong glass retort, which is to be filled with a strong solution of caustic potash, to which a little recently slaked lime has been

* System of Chemistry, vol. i. p. 270. 5th ed.

added, the mouth of the vessel is then to be inverted in a quantity of the same liquid, and hydrogen gas is to be passed into it until the solution contained in the neck have been forced out; the mouth is then to be stopped, and the retort to be transferred to a stand, the mouth being opened under the surface of water in the hydro-pneumatic apparatus. Heat is applied to the body of the retort, and the gas is formed when the solution boils. It appears that the potash exercises a disposing affinity by which the phosphorus is enabled to decompose the water, one portion of it combines with its oxygen, and another with the hydrogen, and the results are phosphoric acid and phosphuretted hydrogen, the former remaining in the liquid, while the latter is disengaged in the elastic form.

When the gas is required in a state of purity, it may be prepared, according to Dr. Thomson, by filling the body of a tubulated retort of the capacity of about 12 cubic inches, with 5 parts of water which has been recently boiled, in order to deprive it of its atmospheric air, and 1 part of muriatic acid. About half an ounce of phosphuret of lime in lumps is to be dropped as speedily as possible into the liquid, and the remaining space in the retort is to be quickly filled with boiled water; the beak is plunged under the surface of water which has also been recently boiled, and contained in the common water apparatus. A gentle heat is then to be applied, the gas rises and may be collected in appropriate receivers.* Half an ounce of phosphuret of lime yields 70 cubic inches of this gas.

CCCCXXIII. Phosphuretted hydrogen thus prepared is a colourless and invisible elastic fluid, of an exceedingly bitter taste, and of a nauseous odour, having some resemblance to that of garlic.

Its specific gravity, air being unity, is by experiment 0.865, and by calculation 0.9022; hence taking 0.865 as its true specific gravity, and the weight of 100 cubic inches of

* Annals of Philosophy, vol. viii. p. 87.

atmospheric air, at mean temperature and pressure, being equal to 30.50 grains, 100 cubic inches of phosphuretted hydrogen will weigh 27.51 grains. Water absorbs only a small quantity of this gas; the proportions, as stated by Mr. Dalton, are 3.7 measures of the latter to 100 of the former; by Dr. Henry as 2.14:100; and by Dr. Thomson as + 2 to 100. It is not decomposed when kept in contact with pure water in close vessels, but when left standing over water impregnated with common air, it soon loses the property of burning spontaneously when admitted to atmospheric air.

CCCCXXIV. The property for which phosphuretted hydrogen is most remarkable is its combustibility, which is such that it takes fire spontaneously on coming into contact with the air. When a bubble rises through water and arrives at the surface, it produces a slight explosion accompanied with a vivid light, and if the air be calm, a coronet of dense white vapour rises unbroken to the height of several feet, the circle continually enlarging as it ascends. This coronet is formed of an indefinite number of small circles, placed in a vertical position, and revolving with great rapidity upon their axes. A similar appearance often attends the discharge of artillery, and no doubt depends upon the direction given to the repulsive forces at the moment of the explosion.

The explosion is more violent and the light still more brilliant in pure oxygen gas, and the former should be admitted to the latter in small quantities at a time. In a narrow tube, however, it may be mixed with oxygen without spontaneous combustion, and it will then be deprived of its phosphorus without change of volume. When employed for exhibition, the phosphuretted hydrogen may be allowed to pass into a receiver of large capacity, filled partly with water, and in part with a mixture of oxygen and atmospheric air, in the proportion of $\frac{1}{4}$ of the former to $\frac{3}{4}$ of the latter, the combustion will be brilliant, and the inconvenience of inhaling the unpleasant vapour will be avoided. The reason of this explosion, or combustion, will be obvious on recollecting that

the gas is formed of two highly inflammable bodies, and that the combustibility of the phosphorus, or its power of uniting with oxygen, is much increased by its minute division in the hydrogen; when, therefore, it is presented to atmospheric air, the phosphorus combines with one portion of its oxygen, and probably forms hypo-phosphorous acid, while the hydrogen unites with another portion, and is converted into aqueous vapour, which constitute the substance of the white smoke observed during the combustion. This spontaneous combustibility, as observed by Dr. Thomson, depends upon the rapidity with which the phosphorus combines with the oxygen and the heat produced, for if the temperature rise as high as 148° it takes place, but if inferior to this point, the phosphorus combines with only half a volume of oxygen, and the hydrogen remains unchanged. Accordingly, phosphuretted hydrogen may be deprived of the whole of its phosphorus, by putting it into a narrow glass tube and passing into it half a volume of oxygen, a white smoke is formed, the oxygen gradually disappears, and there remains behind a quantity of hydrogen amounting exactly to the original volume of phosphuretted hydrogen gas.*

CCCCXXV. When phosphuretted hydrogen is passed into a vessel containing chlorine gas, it burns vividly with a greenish yellow flame, and a brown coloured substance is deposited, which very speedily dissolves in the water. If the two gases be mixed in the proportion of 1 volume of the former to 3 volumes of the latter, a total condensation takes place, and the results are muriatic acid and the brown substance just mentioned, which is considered by Dr. Thomson as the bichloride of phosphorus. By solution in water it is converted into phosphoric and muriatic acids.

If iodine and phosphuretted hydrogen be mixed in a glass tube which has been previously exhausted of common air, a combination ensues between the phosphorus and iodine, which terminates in the formation of a white and solid iodide of

* *Annals of Philosophy*, vol. viii. p. 87.

phosphorus. The best proportions for this purpose are 4 grains of iodine to $1\frac{1}{2}$ cubic inch of phosphuretted hydrogen; in this case, the whole of the phosphorus is withdrawn, and the gas which remains, and is not altered in volume, is simple hydrogen.

Phosphuretted hydrogen mixed with nitric oxide gas in the proportion of 1 volume of the former to 3 of the latter, suffers no change; but if the electric spark be passed through the mixed gases, an explosion is produced, and the bulk of the whole diminished. Nitrous gas contains half its bulk of oxygen, and hence 1 volume of the phosphuretted hydrogen combines with $1\frac{1}{2}$ volume of oxygen. If 2 instead of 3 volumes of nitric oxide be employed, only one half of the phosphuretted hydrogen appears to be decomposed.

This gas also explodes with nitrous oxide when mixed in the proportion of 1 to 3, and 2 volumes of azote remain.

If phosphuretted hydrogen be mixed over water with nitric oxide, and a bubble of oxygen be admitted to the mixture, the consequence is an immediate detonation.

Water impregnated with phosphuretted hydrogen has a yellow colour, an intensely bitter taste, and an odour similar to that of the gas itself. It has no effect upon vegetable colours; but it produces decomposition in solutions of many of the metallic salts, occasioning precipitates, the colours of which are mostly dark.

CCCCXXVI. The composition of this gas may be determined upon the same principle as that of sulphuretted hydrogen. When electric sparks are transmitted through it, phosphorus is deposited and hydrogen disengaged, but the volume of the air remains unchanged; this is also the case, as has been proved by Dr. Thomson, in its decomposition by bodies; hence, as phosphorus in combining with hydrogen produces no change in volume, the relative amount of phosphorus may be ascertained by the difference in specific gravity between hydrogen and phosphuretted hydrogen. These are respectively 0.865 and 0.0732, or as 10.6 to 1, and it may be con-

ceived to be composed of 1 proportion of phosphorus 20, and 1 of hydrogen, and may be represented by 21. To this compound, Dr. Thomson has given the name of *Hydroguret of Phosphorus*.

CCCCXXVII. Phosphorus is capable of combining with double the proportion of hydrogen which exists in phosphuretted hydrogen, and it then exists also in the form of an elastic fluid, which Sir H. Davy first described by the title of *Hydro-phosphoric gas*, and Dr. Thomson, by that of bi-hydroguret of phosphorus.

When solid hydrate of phosphorous acid is heated in a retort out of contact with the air, solid phosphoric acid is produced, and a large quantity of elastic fluid generated, which has very peculiar properties. Its odour is disagreeable, but much less so than that of phosphuretted hydrogen; when mixed with common air, it does not experience spontaneous combustion, but it detonates violently when heated in contact with oxygen to the temperature of 300° . It explodes in chlorine with a white flame. Water absorbs about $\frac{1}{8}$ its bulk. Its specific gravity, compared with hydrogen, was stated by Sir H. Davy as about 12 to 1.

When sulphur is sublimed in this gas, a sulphuret of phosphorus is formed, and nearly 2 volumes of hydrogen are produced. The same increase of volume takes place when it is heated in contact with potassium. It is therefore a compound of 1 proportion of phosphorus and 2 of hydrogen, and its specific gravity will be $0.8650 + 0.0732 = 0.9382$. It will be represented by $20 + 2 = 22$.

CCCCXXVIII. The late researches of Mr. Dalton have thrown some doubt over the existence of two distinct species of phosphuretted hydrogen. From the results of his experiments, he affirms that there is but *one* combination of phosphorus and hydrogen, and that all the varieties of this gas have arisen from the circumstance, that free hydrogen is liable to be produced in greater or smaller quantities in all the processes used for the generation of phosphuretted hydrogen.

Pure phosphuretted hydrogen may be easily withdrawn from simple hydrogen by the salt called *oxy-muriate of lime*, by which it is absorbed with great rapidity. The process employed by Dr. Thomson with phosphuret of lime is considered by Mr. Dalton as the best for procuring the gas, provided it have been carefully secluded from the atmosphere, but if it have been exposed only for a few hours, the gas will be much more copious, and contain from 50 to 80 per cent. less or more of free hydrogen.

Pure phosphuretted hydrogen may be mixed with safety in tubes $\frac{3}{10}$ of an inch in diameter, with pure oxygen; and in due time the mixture may be transferred into any sort of vessel without explosion, and kept many hours without sensible alteration; but if an electric spark be sent through it, a violent explosion takes place, attended with a light surpassing in brilliancy that of any other gas. It is thought dangerous to explode at once more than 15 water grain measures of phosphuretted hydrogen. One volume of this gas requires 2 volumes of oxygen gas for its complete saturation, and the results are water and phosphoric acid. When electrified for 2 hours, it expands $\frac{1}{3}$ nearly of its original volume, deposits phosphorus, and the residual air is a mixture of hydrogen and phosphuretted hydrogen.

Water freed from air absorbs fully $\frac{1}{8}$ of its volume of this gas, which is the same proportion in which the Hydro-phosphoric gas of Sir H. Davy is condensed, and hence from this and other properties, that gas is supposed to have been nearly pure phosphuretted hydrogen. The gas is expelled from its aqueous solution by boiling, but it is attended with a loss of some of its hydrogen. Mr. Dalton finds that $3\frac{1}{2}$ volumes of nitric oxide are necessary to the complete decomposition of this elastic fluid, that phosphoric acid and water are formed, and that azotic gas remains in the proportion of 2 or 3 per cent. less than $\frac{1}{2}$ the volume of the nitrous gas. Dr. Thomson had remarked that no alteration followed the mixture of nitric oxide and phosphuretted hydrogen; there is no imme-

diate action, but if they be in contact a few hours, the whole of the phosphuretted hydrogen will be consumed, if the nitrous gas be in excess, and there is left a mixture of nitrous gas, nitrous oxide, and azotic gases amounting to about $\frac{1}{2}$ the volume of the original mixture. As an explosion takes place when a bubble of oxygen is admitted to a mixture of nitric oxide and phosphuretted hydrogen, so it was found by Mr. Dalton, that a detonation was the consequence of passing a bubble of nitric oxide into a mixture of phosphuretted hydrogen and oxygen. Nitrous oxide and phosphuretted hydrogen explode by a spark, but undergo no change by simple mixture for several hours at least. The due proportions are 3 to 1.*

Phosphorus decomposes the different compounds of azote and oxygen. When introduced in a state of active combustion into nitrous oxide, the inflammation not only continues, but is more brilliant than in atmospheric air; it is still more vivid in nitric oxide, so much so, in fact, as to be scarcely inferior to the light emitted while consuming in pure oxygen. In both cases the gases are decomposed and phosphoric acid produced. Phosphorus is also acidified by nitric and nitrous acids.

CCCCXXIX. Phosphorus is apparently insoluble in oxygen gas, but it is dissolved by azote; the quantity, however, is apparently small, the volume of the gas is augmented about $\frac{1}{40}$, and when oxygen is admitted to it, the mixed gases immediately become luminous.

Phosphorus decomposes some of the compounds of carbon. When transmitted in the state of vapour over carbonate of lime, or marble while heated, a quantity of carbon will be found after the experiment to have been deposited. In this case, the carbonic acid previously combined with the lime yields its oxygen to the phosphorus, and the base appears in its simple state.

* *Annals of Philosophy*, vol. xi. p. 8.

No experiments have been made upon phosphorus in contact with silicon, or boron.

A compound may be formed of phosphorus and carbon, after the method of Dr. Thomson, by adding to the liquid which remains after phosphuret of lime has ceased to give out phosphuretted hydrogen gas from water, a considerable excess of muriatic acid, filtering the liquid after agitating it, and collecting and drying the precipitate.

Phosphuret of carbon is a soft powder of a dirty lemon colour, destitute of taste and odour. When exposed to the air, it absorbs moisture, gives out the smell of phosphuretted hydrogen gas, and acquires an acid taste. It does not melt when heated, nor is it altered or decomposed at a temperature higher than 212° . Exposed to a degree of heat, short of redness, it burns, and at a higher temperature gradually gives out phosphorus, and the residue consists of carbon covered with a coating of phosphoric acid. When the powder is thrown over a fire in small quantities at a time, beautiful flashes of light are observed. It is composed, according to Dr. Thomson, of 1 proportion of phosphorus and 1 of carbon.

CCCCXXX. The uses to which phosphorus is applied are very limited. It is in some cases employed by the chemist as a reagent, or as a material in forming compounds which are subsequently used in the production of other bodies. It has been introduced into the materia medica, and combined with oils, ethers, or alcohol, or with oxygen in the form of phosphorous acid, has been prescribed by the European physicians in very small quantities as a powerful stimulant, and it has been said to exhibit a specific effect upon some of the organs. When taken into the stomach in its simple form, it is soon converted into one of the acids, and then operates like a poison, producing inflammation and gangrene. One of the uses to which it is applied by the chemist is as an eudiometric substance in the analysis of atmospheric air. For this purpose a portion of air is measured in a tube graduated into 100 parts, and is then transferred to one of a larger size filled

with water, standing over that liquid, and containing a glass rod supporting a stick of phosphorus; a portion of the phosphorus is immediately dissolved by the azote, and in a state of minute division coming into contact with the oxygen of the air, the two combine, forming hypo-phosphorous acid, which sinks in the form of a white vapour to the bottom of the tube; there it meets with the water, and from the affinity between them it is condensed, a vacuum proportional to the volume of the oxygen withdrawn is produced, and the water rises in the vessel. These processes go on until the whole of the oxygen is removed, the residual air is then transferred to the graduated tube, and after making a deduction of $\frac{1}{10}$ part of the volume for the increase in bulk from the phosphorus dissolved in the azote, the quantity of oxygen contained in the air submitted to trial may be ascertained by its diminution in bulk. This method was proposed by M. Berthollet. It is simple and convenient, and is completed, according to the size of the mass of phosphorus, in from 2 to 8 hours.

The air may likewise be analysed by the active combustion of phosphorus. A grain or two of this substance may be introduced into a small retort with a long neck and of a known capacity. The neck is partly filled with water, and immersed in the same liquid; heat is applied to the phosphorus; it takes fire and the expansion of the air first forces the water lower in the neck, but in consequence of the condensation of the oxygen it again rises, and when the temperature has fallen to that of the air, the quantity of oxygen may be estimated by the diminution in volume in the residual air. The analysis by the slow combustion of phosphorus is preferable.

Phosphorus, either alone or combined with sulphur, is also employed in the formation of phosphoric bottles. The former have been already mentioned, and the latter will be described under the head of sulphur.

CCCCXXXI. Phosphorus is highly inflammable, and when exposed to the air in considerable quantities the heat

evolved by its combination with oxygen is such as to cause it often to take fire, and burn with great vehemence; moderate friction even with a small mass is sufficient to cause its inflammation, and when once on fire it not only adheres with great pertinacity to the body with which it is in contact, but can be extinguished only with great difficulty. From this great disposition to active and spontaneous combustion, many accidents have happened to those who were careless or ignorant. It should therefore always be kept in a vessel filled with water, and if of glass this vessel should be protected with a case of tin or lead, as it is well known that glass will often crack and sometimes fall to pieces without any obvious cause. In using phosphorus it will be proper to have water at hand, into which it may be occasionally dipped to prevent its spontaneous inflammation.

SECTION VII.

Of Sulphur.

CCCCXXXII. This well known substance exists in considerable abundance in nature. It is found in the neighbourhood of volcanoes, and also in smaller quantities imbedded in strata of gypsum and limestone, or constituting the matter of veins traversing some of the primitive rocks. It likewise forms a constituent part of some species of minerals, particularly the pyrites or sulphurets of iron and copper, and may be obtained from them by sublimation.

Sulphur is of a light yellow colour with a shade of green, hard, brittle, and of a specific gravity equal to 1990. When found native, it is often crystallized in octoedra, which vary from translucent to transparent; it is a non-conductor of electricity, but possesses the power of polarizing light. The refractive power of sulphur in this state is high, and compared with that of the diamond, its ratio, according to Dr. Brewster, is as 2.115 to 2.439. Its capacity for heat is stated at 0.19 by Mr. Dalton, and 0.183 by Mr. Kirwan.

Its representative number is 15.

It conducts heat slowly, whence it happens, that when a roll of sulphur is held in the hand, it often cracks and falls to pieces, an effect which may be ascribed to the difference of expansion in the parts that are unequally heated.

By friction it is rendered electrical, and its electricity is negative, or resinous.

CCCCXXXIII. When sulphur is exposed to the temperature of about 220° , it melts and assumes a dark reddish colour; if the heat be increased to 560° , it rises in the form of vapour, and when in contact with the atmosphere takes fire, burning with a blue attenuated flame, and exhaling a pungent, suffocating odour. If sulphur, while thus heated, be confined in a close vessel, it sublims without alteration, and condenses

upon the cooler part of the receiver in the form of a light, yellow powder. Advantage is taken of this property in its purification. Sulphur, as first obtained, is mixed with more or less of foreign bodies, and the first process is to melt it in a close vessel, by which the impurities are caused to subside, the liquid is then run into cylindrical moulds in which it concretes, and is known in commerce by the name of *roll brimstone*. When sublimed and obtained in a powdery state, it is pure, and is called *flowers of sulphur*.

The fluidity of melted sulphur does not keep pace with the increase of heat; on the contrary, it becomes viscid, and this state increases in an extensive range of 200° . If the temperature be reduced, the melted matter, before it concretes again, becomes more liquid. If while thus tenacious it be poured into cold water, it remains ductile for some time, and artists have availed themselves of this property in the formation of sulphur casts or impressions, which may be executed with great delicacy.

Sulphur is insoluble in water; but in certain circumstances an affinity appears to exist, and a combination may be formed between them. If an acid be poured into the liquid called hydro-sulphuret of potash, which is a solution of the compound of the alkali and sulphur, the latter will be precipitated of a delicate white. The same change in the colour is produced when sulphur is sublimed in a vessel filled with aqueous vapour, or even when water is dropped upon its surface while liquid. This whiteness then most probably depends upon the presence of water, and in this state the body is to be considered as an *hydrate*.

CCCCXXXIV. This substance combines with oxygen in two different proportions, and forms compounds which are distinguished from each other by very characteristic properties. They are both acid; the one which contains the smallest proportion of oxygen is called *Sulphurous acid*, and that in which the elements are mutually saturated, *Sulphuric acid*.

1. *Sulphurous acid.*

CCCCXXXV. While sulphur is burning in the open air, it is well known to exhale a peculiar pungent and suffocating odour. The product of this combustion is the sulphurous acid. This compound was known to Stahl, but it was first procured in its gaseous state by Dr. Priestley. Some of its properties and relations were examined by Berthollet, and they were completely unfolded by the subsequent experiments of M. M. Fourcroy and Berthollet, and of Dr. Thomson.

This acid may be obtained either by the combustion of sulphur in atmospheric air, or in pure oxygen. When previously inflamed and introduced into a vessel filled with the gas, it burns vividly, at first with a beautiful violet flame, which gradually changes to a rose colour, and the receiver becomes filled with whitish fumes which possess acid properties. The most convenient method, however, and the one which is always followed to procure sulphurous acid, is to decompose sulphuric acid by some of the metals which have not the property of separating the elements of water, such as copper, or mercury. A quantity of quicksilver is put into a small tubulated retort, the beak of which opens under the surface of the same fluid in the mercurial apparatus; sulphuric acid in the proportion of double the weight is poured upon the metal, and the body of the retort is exposed to the heat of a spirit-lamp. When the temperature has risen nearly to the boiling point of the acid, it is decomposed, one proportion of oxygen is transferred to the mercury, the remaining compound of sulphur and oxygen rises in the form of a gas, whitish and opaque, and is propelled into the receiver. After standing at rest for a short time, the opacity disappears.

CCCCXXXVI. Sulphurous acid thus obtained is a permanently elastic, invisible fluid, of a sour taste, and of an highly suffocating and pungent odour, which, even if diluted largely with atmospheric air, produces, when taken into the lungs, cough and difficulty of respiration. In its pure state it is in-

stantly fatal to animal existence. Its specific gravity, according to M. Thenard, is 2.234 ; but by calculation from its composition, that of oxygen being considered as 1.1088, it will be 2.217 ; compared with that of hydrogen it is as 30 to 1 ; 100 cubic inches will weigh 67.61 grains.

This gas is incapable of supporting combustion. It acts upon vegetable blues, first turning them red, and afterwards producing a tint of yellow.

When a vessel containing this gas is inverted under the surface of water, an absorption takes place, and when aided by agitation, the whole is speedily condensed. Water when saturated contains, according to Dr. Thomson, 33 volumes, and according to Saussure Jun. 43.78 volumes of this gas. The solution has an acid taste, and a pungent, disagreeable odour ; when heated the sulphurous acid reassumes its elastic form ; but it is still retained when the solution is allowed to freeze. The liquid sulphurous acid slowly absorbs oxygen from the air, and is converted into sulphuric acid.

Sulphurous acid gas and oxygen when mixed in a dry state in the proportion of 2 volumes of the former to 1 of the latter, suffer no change ; but if a small portion of water be added, they gradually combine and form sulphuric acid. When the mixed gases are passed through an ignited porcelain tube, the combination is effected much more rapidly, and the product, as in the former case, is sulphuric acid.

CCCCXXXVII. Chlorine acts upon sulphurous acid, provided water be present, and by the decomposition of the liquid, sulphuric and muriatic acids are formed. Nitric acid is decomposed, by this gas, and the products are nitrous acid gas and sulphuric acid. When mixed with hydrogen and transmitted over the ignited surfaces of porcelain, it is decomposed, and the elements sulphur, oxygen, and hydrogen unite so as to form water and sulphuretted hydrogen gas, while a portion of the sulphur is precipitated.

Sulphurous acid unites with the salifiable bases, and forms compounds which are known by the name of *Sulphites*. Their

taste is sulphureous, they are decomposed at a high temperature, and by many of the other acids, and they are converted into *sulphates* by exposure to the air, or to the action of compounds containing oxygen. They are all more or less soluble in water.

-Sulphite of ammonia may be formed by the direct action of its constituent parts. When equal volumes of sulphurous acid and ammonia are mingled over mercury, a white cloud or vapour is formed which soon condenses into a solid salt of a yellowish white colour, of a cool, penetrating taste, and deliquescent on exposure to the air. When dissolved in water and the solution is afterwards evaporated, it may be obtained in regular six-sided prisms terminated by six-sided pyramids. It is very soluble in water, and by the action of the air is speedily converted into a sulphate. It consists of 2 proportions of acid 60, and 1 proportion of ammonia 16, and will be represented by 76.

Sulphurous acid, from its property of destroying vegetable colours, is used in the art of bleaching, the article being merely exposed to the fumes of burning sulphur.

It has been shown by Sir H. Davy that when sulphur is consumed in oxygen gas there is no alteration in the volume of the air; and as sulphurous acid is the product of this combination, the proportions of its constituent parts may be ascertained by the difference in weight between oxygen and sulphurous acid. Now the weight of 100 cubic inches of the latter is double that of the same bulk of the former; the sulphur and oxygen exist in it therefore in equal weights; but as sulphuric acid contains 150 of oxygen to 100 of sulphur, the oxygen in the sulphurous acid must be considered as 2 proportions. Hence, the sulphurous acid gas will consist of

	Prop.	Atoms.	Weight.
Sulphur - - -	1 - - -	1 - - -	50
Oxygen - - -	2 - - -	2 - - -	50
	<hr/> 3	<hr/> 3	<hr/> 100

Its representative number will be $15 + 15 = 30$.

2. *Sulphuric acid.*

CCCCXXXVIII. When the aqueous solution of sulphurous acid is exposed for some time to the air, it absorbs oxygen, and if it be then exposed to heat, water alone is driven off, and the remaining liquid becomes exceedingly acid. This acid which is one of the most important of this class of bodies, is the oil of vitriol of the older chemists, the Sulphuric acid of the French nomenclature.

It was discovered by the alchemists, and for some time was obtained by the distillation of the green vitriol of commerce.

It is now produced in immense quantities for the arts, by decomposing nitre by sulphur. This substance is mixed with from $\frac{1}{7}$ to $\frac{1}{10}$ its weight of the salt, the mixture is put into a large chamber lined with lead, and having its floor covered with water to the depth of one or two inches, it is inflamed, and excluded from the atmosphere. The nitrate of potash is decomposed, and its oxygen combines with the sulphur at the temperature of ignition, sulphuric acid is formed, and its vapour coming into contact with the water is absorbed and forms a weak acid. The minute actions which take place in this process are described by Sir H. Davy. The sulphur is first converted into sulphurous acid gas, and the nitric acid into nitrous gas, the last of which coming into contact with atmospheric oxygen contained in the chamber is changed to nitrous acid vapour, and if water be not present, this vapour and sulphurous acid combine and form a white crystalline solid. This compound is instantly decomposed by water, oxygen from the acid vapour is communicat-

ed to the sulphurous acid, which then becomes sulphuric acid, and nitrous gas is again disengaged, and the process continues, according to the same principle of combination and decomposition, until the water at the bottom of the chamber becomes strongly acid. In proof that this theory of the formation of sulphuric acid is correct, it is remarked by Sir H. Davy, that when equal volumes of nitrous acid gas and sulphurous acid in a dry state are mingled together, no action takes place; but if a drop of water be introduced into the vessel, there is an immediate condensation, and formation of a beautiful white crystalline solid. If the water be more abundant, nitrous gas will be rapidly evolved, and the water will be found to be a solution of oil of vitriol. From the products of its decomposition this white substance is inferred to be a compound of 4 volumes of sulphurous acid, and 3 of nitrous acid vapour; and 2 or 3 proportions of it are combined with 1 proportion of water. This is the substance which has been supposed by Mr. Dalton to be sulphuric acid in a solid state.* When the action between the materials is at an end, and the vapour has been absorbed, the liquid is drawn off and concentrated by evaporation in large glass vessels. The sulphurous acid and superfluous water are expelled, and the fluid which remains is the oil of vitriol or sulphuric acid of commerce.

In this state it is sufficiently pure for the arts, and for ordinary chemical experiments, but when required for analytical researches, it must be purified, for it contains a portion of the sulphates of lead and of potash. This is effected by diluting it with pure water, and allowing it to remain for some time at rest, the sulphate of lead precipitates, the liquid is then decanted, it is again concentrated, and afterwards distilled.

CCCCXXXIX. Sulphuric acid is a transparent, colourless liquid, of an oily consistence, and of a specific gravity equal to 1.845, compared with water as 1.000. But the best commercial oil of vitriol contains, according to Dr. Ure, from one

* Davy's Elements of Chem. Philos. part 1. p. 276

half to three quarters of a part of foreign matter, and the ordinary kind often from 3 to 4 per cent. Its real specific gravity is 1.8452, which increases with the proportion of saline matter, so that the strength of the acid is not always to be judged of by its relative weight.* Sulphuric acid is corrosive in a high degree; when applied to the skin it produces the sensation of heat, which is followed by inflammation and even erosion. Its taste, even when very largely diluted with water, is exceedingly acid, and a single drop will instantly change the colour of a large quantity of solution of a vegetable blue to a red.

CCCCXL. Its attraction for water is exceedingly strong, and when exposed to the air, aqueous vapour is absorbed, and the acid increases in bulk, but diminishes proportionally in strength. It is miscible with water in all proportions, and the temperature of the mixture is augmented. One part of water poured into two parts by weight of concentrated sulphuric acid, and mingled by agitation, causes the thermometer to rise from 50° to 250° . The volume of the mixed liquid, after it has fallen to the temperature of the air, is found to be less than the bulks of the acid and water before the experiment; a condensation, therefore, takes place, and the production of heat is generally supposed to depend upon this increase of density, and proportional diminution of capacity.

The attraction of sulphuric acid for water is so powerful, that it has never been obtained free from this liquid. In its strongest state it contains, according to Mr. Kirwan, but 78.59 parts, and, according to Sir H. Davy, 81 parts of real acid. Hence it has been inferred that this liquid acts the part of a base, and gives fixity to the acid. It is doubtful, however, whether it be the water as such, or its elements which are combined with those of the acid. Sir H. Davy has given it the name of Hydro-sulphuric acid.

* Journal of Science and the Arts, vol. iv. p. 114.

The following table contains some of the results of Dr. Ure's experiments upon the quantity of real or dry acid existing in 100 parts of dilute acid, at different densities.

Liquid.	Spec. grav.	Dry.
100	1.8485	81.54
95	1.8376	77.46
90	1.8115	73.39
85	1.7676	69.31
80	1.7120	65.23
75	1.6520	61.15
70	1.5975	57.08
65	1.5390	53.00
60	1.4860	48.92
55	1.4360	44.85
50	1.3884	40.77
45	1.3440	36.69
40	1.2999	32.61
35	1.2572	28.54
30	1.2184	24.46
25	1.1792	20.38
20	1.1410	16.31
15	1.1019	12.23
10	1.0682	8.15
5	1.0336	4.08

When sulphuric acid is poured upon snow, a rapid liquefaction takes place, and the temperature is reduced; but the effect is much more positive if the acid have been previously diluted with water; because, when concentrated, the union with the water, which is formed, causes an evolution of heat and preserves in some measure the temperature of the mixture.

CCCCXLI. Sulphuric acid of the specific gravity of 1.848 congeals at -15° ; and when diluted with rather more than half its weight of water, it requires a reduction of temperature equal to -36° . But if it be diluted until its specific gravity is 1.780, in which state it contains, according to Sir H. Davy,

just twice as much water as the acid of 1.845, it may be frozen by surrounding it with snow or ice, or at any temperature below 46° . When thus crystallized, it appears in the form of a six-sided prism, of considerable hardness, and heavier than the liquid acid.

When exposed to heat, sulphuric acid boils at the temperature of 550° , or, according to Mr. Dalton, at 620° , and distils over unaltered. In consequence of the high degree of heat required for its vaporisation, and the sudden production of portions of vapour, some caution is required to conduct the distillation with safety.

Sulphuric acid is not acted upon by the supporters of combustion, nor by azote, but it is decomposed by hydrogen gas, as was observed by Priestley and Fourcroy, when transmitted together over the surface of ignited porcelain, and the results are water and sulphur. It absorbs nitric oxide gas and acquires a purple colour. It is also capable of combining with nitric acid, and Mr. Keir has proposed a cheap and effectual acid for the purpose of separating silver from its alloys, by dissolving 1 pound of nitre in 8 or 10 pounds of sulphuric acid. This acid is decomposed by sulphur, which attracts one proportion of oxygen, and the whole is converted into sulphurous acid.

Sulphuric acid combines with the salifiable bases, and forms a class of very important salts which are known by the name of *Sulphates*.

CCCCXLII. Sulphate of ammonia may be formed by dropping into the diluted acid, the substance called salt of Hartshorn, until all action between them ceases, and afterwards evaporating the liquid; by pouring sulphuric acid upon muriate of ammonia; or by the maceration of the soot of coal in water. It crystallizes in the form of the six-sided prism, the planes of which are unequal, and terminated by six-sided pyramids. When exposed to heat it decrepitates, the odour of ammonia becomes perceptible, and a salt with excess of acid sublimes. It is soluble in water, and its taste

is bitter and acrid. From the results of analysis, it appears to be composed of 1 proportion of sulphuric acid 37.5, 1 of ammonia 16, and 1 of water 8.5, and it may be represented by 62. It is employed in the arts for the purpose of obtaining sal ammoniac, being mixed with common salt and exposed to heat in a close vessel.

CCCCXLIII. When sulphurous acid gas is transmitted through sulphuric acid, it is condensed in considerable quantity, the liquid changes to a yellowish brown, and exhales a suffocating odour. When distilled the first portion which passes over crystallizes in long white prisms which emit a dense vapour, and deliquesce on exposure to the air. It is considered as a compound of the two acids. Brought into contact with water, it is decomposed with violence accompanied with a hissing noise. It is this compound which was obtained by the older chemists at a certain stage of the distillation of green vitriol, and to which they gave the name of Glacial oil of Vitriol. Dr. Thomson considers the solid fuming substance which is formed by distilling to a certain degree, the dark coloured acid obtained from vitriol at Nordhausen in Germany, as sulphuric acid in a state of absolute purity;* but from the facts just stated, it is questionable whether it may not rather be viewed as a compound; and if the opinion of Sir. H. Davy and of Dr. Murray, that the sulphuric acid is a compound of sulphur, oxygen and hydrogen. should prove correct, it will appear that the acid is incapable of existing in the solid state.

CCCCXLIV. It has been sufficiently proved, that the oxygen in sulphuric acid is to that contained in sulphurous acid in the ratio of 3 to 2; and it is composed of

		Prop.				Atoms.				Weights
Sulphur	-	1	-	-	-	1	-	-	-	40
Oxygen	-	3	-	-	-	3	-	-	-	60
		<hr/>				<hr/>				<hr/>
		4				4				100

* System of Chemistry, vol. ii. p. 105.

The dry acid may be represented by $15 + 22.5$, or 37.5 ; and the concentrated liquid acid by $37.5 + 17$, the last of which represent 2 proportions of water.

This acid is one of the most important of this class of bodies. It is extensively employed in the arts of dyeing and of bleaching; and it is of great value to the chemist, as it affords an active agent which may be used with facility in effecting a great variety of decompositions, or in transferring oxygen to other bodies. It also forms an article of the *Materia Medica*.

Chloride of Sulphur.

CCCCXLV. Sulphur and chlorine combine with each other and form a peculiar, volatile liquid, which was discovered in 1804 by Dr. Thomson.* It may be prepared either by the process of Dr. Thomson, which consists in passing a current of chlorine through flowers of sulphur, or by heating sulphur in a vessel filled with chlorine, according to the method of Sir H. Davy, a combination in either case ensues between these elements, and the result is a liquid, the colour of which by reflected light is a fine red, by transmitted light, a yellowish green. It is the sulphurane of Sir H. Davy, the chloride of sulphur of Dr. Thomson. The odour of this chloride is strong, resembling that of marine plants, it is peculiarly acrid and affects the eyes like ammonia, and its taste is acid, hot and bitter. Its specific gravity is 1.7.

Chloride of sulphur has no effect upon dry litmus paper, but if moisture be present, its colour is changed to a red.

When agitated in water it is decomposed, sulphur is precipitated, and the liquid is found to contain sulphuric and muriatic acids. When added to nitric acid, a mutual decomposition of the two liquids takes place with violence, nitric oxide gas and chlorine are evolved, and sulphuric acid is formed. This chloride readily dissolves sulphur, and acquires a brown colour.

* Nicholson's Journal, vol. vi. p. 102.

System of Chemistry, vol. i. p. 285. 5th ed.

According to the experiments of Sir H. Davy, 10 grains of sulphur absorb 30 cubic inches of chlorine. It is therefore a compound of 1 proportion of sulphur 15, and 1 of chlorine 33.5, and 48.5 are to be considered as the number by which it is to be represented.

CCCCXLVI. Sulphur and iodine also unite with each other, and form a compound of a dark greyish colour, crystallized and radiated like sulphuret of antimony. The elements in this *iodide* of sulphur are held together by a weak affinity, and they are separated both by the action of heat, and by distillation with water.* The proportions in which they exist in the compound have not been accurately determined.

Sulphuretted Hydrogen.

CCCCXLVII. Sulphur is capable of combining with hydrogen, and of forming a peculiar gaseous fluid, which for some time was known by the name of Hepatic air, but is now called Sulphuretted hydrogen. It is a production of nature, and constitutes the active principle of the sulphureous waters, or, as they are here termed, Sulphur springs. The waters of Harrowgate in England have been long celebrated; and mineral waters of the same nature are not uncommon in the United States. The margins of these springs are usually covered with sulphur, from the decomposition of the gas on exposure to the air.

Sulphuretted hydrogen was first examined by Mr. Scheele, and the labours of succeeding chemists have unfolded its properties and relations.

This compound may be formed by subliming sulphur in dry hydrogen gas, or by the action of the sulphurets of some of the metals upon a diluted acid. The mode commonly practised is to form sulphuret of iron by exposing a mixture of 1 part of flowers of sulphur, and 3 parts of iron filings in a covered crucible to a degree of heat little short of redness. A

* Gay-Lussac,—Memoir on Iodine.

combination takes place, the mass is then powdered, put into a tubulated retort connected with a water-trough, and muriatic acid or sulphuric acid diluted with water is added. An effervescence immediately takes place, and an elastic fluid passes into the receiver. The iron decomposes the water, attracts its oxygen and disengages the hydrogen, and this element in its nascent state combines with a portion of the sulphur, forming sulphuretted hydrogen. The gas obtained by this mode is impure, and for delicate or accurate experiments, it should be procured from sulphuret of antimony and muriatic acid, and be caught over mercury.

CCCCXLVIII. Sulphuretted hydrogen is a permanently elastic, invisible fluid, possessing the mechanical properties of atmospheric air; it is characterized by a peculiarly offensive odour, similar to that evolved from bilge-water, or bad eggs. Its specific gravity, compared with that of atmospheric air, is as 1.1967 to 1.0000, and with hydrogen, as about 16 to 1; 100 cubic inches weigh 36.50 grains.

It extinguishes flame and is fatal to life.

Sulphuretted hydrogen is inflammable. When a flame is applied to the mouth of a jar filled with the gas, it takes fire, burns with an attenuated blue flame, and a portion of its sulphur is deposited. The products of this combustion are water and sulphurous acid. When previously mixed with oxygen gas in equal volumes, it explodes when ignited.

CCCCXLIX. If a jar filled with this gas be inverted over water, an absorption gradually takes place, and after a time, it is entirely condensed. The union may be produced in a shorter time by agitation. Water, according to M. Gay-Lussac, absorbs 5 times its volume of this gas; the solution is at first transparent and colourless, and exhales the odour of sulphuretted hydrogen; but on standing for a few days it grows turbid, deposits sulphur and ceases to give out any smell. It is decomposed by nitric acid, and sulphur is precipitated. This solution, when poured into the solutions of the metallic salts, forms precipitates, the colours of which vary

with the nature of the metal. Most of them are brown, and as a minute portion of sulphuretted hydrogen is sufficient for this purpose, its aqueous solution has been employed as a test, particularly of the salts of lead. The metals, in fact, are tarnished by coming into contact with the gas.

Sulphuretted hydrogen gives a tinge of red to the delicate vegetable blues; it also combines with some of the bases, forming compounds which exhibit the properties of salts; hence, it appears to possess the qualities of a weak acid, and has been named by Gay-Lussac hydro-sulphurous. It is an hydricid.

CCCCCL. When the electric spark is transmitted through sulphuretted hydrogen, a decomposition takes place, sulphur is precipitated, and hydrogen is evolved, but the volume of the air remains unchanged. A very beautiful experiment may be made by subjecting this elastic fluid to the action of a voltaic battery composed of 600 or 800 double plates. The air is to be transferred from a jar into an exhausted globular receiver, in which have been previously inserted two wires, their points being terminated with cones of well prepared charcoal. On connecting the wires respectively with the poles of the battery, and bringing the points of charcoal near to each other, a brilliant and continued sphere of light will be seen between them, the gas is at the same time undergoing decomposition, and the vessel becomes filled with white vapours.

Sulphuretted hydrogen is decomposed by chlorine, white vapours are formed, sulphur precipitates, and its hydrogen combining with the chlorine forms muriatic acid.

With iodine the action is similar, sulphur is separated, and hydriodic acid produced. Mixed with nitric oxide gas in the proportion of 2 volumes of sulphuretted hydrogen to 3 of the nitric oxide, it suffers no change, but when ignited, the gases burn with a yellowish green flame.

Sulphurous acid, and sulphuretted hydrogen when mingled mutually decompose each other, the oxygen of the former

combines with the hydrogen of the latter, and the sulphur of both is precipitated.

CCCCLI. This gas combines with some of the salifiable bases, and forms peculiar compounds, which have acquired the name of *Hydro-sulphurets*. If equal volumes of ammonia and sulphuretted hydrogen be mingled over mercury, a white cloud is produced, and a solid, having the characters of a salt, is deposited in the form of needle-shaped crystals. It is soluble in water, and the solution exhales a foetid odour, but after exposure for some time to the air, it deposits sulphur, and sulphate of ammonia is formed. The hydro-sulphuret of ammonia is employed in the liquid form, and it may be conveniently prepared by transmitting a stream of sulphuretted hydrogen through pure liquid ammonia contained in Nooth's or Woulf's apparatus, until the solution acquires a yellow colour. When recently prepared, it exhales an intolerable odour, but on long standing, a portion of the sulphur is precipitated. It is employed in chemistry as a test of some of the metals.

CCCCCLII. When powdered sulphur is digested for some time in the hydro-sulphuret of ammonia, it combines with the sulphuretted hydrogen, and forms Super or Bi-sulphuretted hydrogen. This compound which contains 2 proportions of sulphur, exists in the liquid form, and it may be prepared by pouring the hydro-sulphuret of potash, or of the other bases, by small portions at a time, into muriatic acid. Part of the sulphur precipitates, and part combines with the sulphuretted hydrogen, forming a liquid of an oily appearance.

This compound is likewise capable of uniting with different bases, and of producing bodies to which Mr. Chenevix has given the name of *Hydroguretted Sulphurets*.

CCCCCLIII. The composition of sulphuretted hydrogen may be gained either from its decomposition by detonation with oxygen, or from the difference in weight between this compound, and an equal volume of pure hydrogen. When one volume of sulphuretted hydrogen is mixed with $1\frac{1}{2}$ of oxygen over mercury and exploded by the electric spark, water

and 1 volume of sulphurous acid are formed. Hence it appears that the volume of oxygen combines with a volume of sulphur, and the half volume of the former with the hydrogen. When sulphur combines with hydrogen the volume of the gas remains unaltered, and the weight of the former may be obtained by subtracting from 36.50, the weight of 100 cubic inches of sulphuretted hydrogen, 2.23, the weight of an equal volume of hydrogen; the product 34.27 gives the amount of the sulphur in 36.50 grains of the gas. From these data we may conclude that sulphuretted hydrogen is composed of

	Prop.	Atoms.	Weight.
Sulphur	1	1	93.89
Hydrogen	1	1	6.11
	<hr/> 2	<hr/> 2	<hr/> 100.00

Its number is $15 + 1 = 16$; and the number for Super-sulphuretted hydrogen $30 + 1 = 31$.

Sulphur with Phosphorus.

CCCCLIV. Sulphur and Phosphorus combine with each other apparently in all proportions, and form a compound which may be considered either as a sulphuret of phosphorus, or phosphuret of sulphur, according as the one or the other predominates in the composition. The combination is produced by melting them together in a tube exhausted of air, or by putting the materials in small quantities into a flask containing water, and gradually raising the temperature to 212° . This method, however, is dangerous, as the compound decomposes water, and often produces an explosion. This accident frequently takes place when the substances are in equal proportions, and the heat of the water is quickly raised. Phosphuret of sulphur melts more readily than either of its constituents, but its fusibility diminishes in proportion to the

amount of the sulphur. It slowly decomposes water, and produces sulphuretted and phosphuretted hydrogen, and phosphorous acid. It also attracts and decomposes the aqueous vapour of the atmosphere.

The most perfect compound of these elements appears to be formed of $1\frac{1}{2}$ part of sulphur, and 2 parts of phosphorus. It is liquid at 40° ; when solid, it is yellowish white; it is more inflammable than phosphorus, and requires a strong heat for its sublimation.* This compound constitutes the best of the preparations of phosphorus for phosphoric bottles. According to Mr. Faraday, explosions are apt to take place when the compounds of sulphur and phosphorus are brought into contact with water, from the presence of oxide of phosphorus and other impurities. They are more fusible than either of their elements, sometimes not becoming solid at common temperatures.

If one of these compounds be shaken with solution of ammonia, and be left for a few hours in it, all the impurities disappear; the reddish or brown colour is removed, and a pure compound of a light yellow colour, semi-transparent, and of greater fluidity, is obtained.

If the ammonia be removed and the substance be transferred into water, it does not perceptibly act upon it for several weeks. If phosphorus and sulphur be added alternately to a portion of it, any quantity of the two substances may be combined, and in any proportion.

A compound prepared in this way, and which was thought to contain 5 of sulphur to 7 of phosphorus, did not become solid at the temperature of 20° Fah. and was very fluid at 32° . On remaining for some weeks in a bottle containing water, it deposited crystals of pure sulphur, and a compound remained not so fusible as the former, but on exposure to an atmosphere of 38° , or 40° for 12 or 14 hours, it became a crystalline mass. Mr. Faraday attempted to analyze this compound by converting the elements, through the medium

* Sir H. Davy.

of nitric acid, into acids. The proportions were 8 of phosphorus to 4 of sulphur, and by directly combining them in this ratio, a compound was formed exhibiting similar properties. These proportions, however, were considered merely as approximations; but it is worthy of notice that the fluid compound of 5 sulphur and 7 phosphorus is nearly as 1 proportion of the former to 2 of the latter; and the compound of 4 and 8, as 1 to 3 proportions; the number of sulphur being 15, and that of phosphorus 10.*

Sulphuret of Carbon.

CCCCLV. When sulphur is slowly sublimed over the surface of charcoal heated to ignition in a tube of porcelain, which is connected with a smaller tube opening under water, a peculiar liquid, possessing very curious properties, is formed. This compound was discovered by Lampadius, who considered it as composed of sulphur and hydrogen, and gave to it the name of *Alcohol of sulphur*. It was successively examined by M. M. Berthollet, Vauquelin and Robiquet, and Berthollet Jun. who drew the same conclusion, in which Sir H. Davy coincided.† M. M. Clement and Desormes, on the other hand, regarded it as a compound of sulphur and carbon, and the correctness of this opinion has been demonstrated by Berzelius and Marcet.‡ M. Cluzel supposed it to be a quaternary compound of sulphur, carbon, hydrogen, and azote.

After the first distillation it is nearly opaque, and of a pale yellow colour; to obtain it pure, a second distillation is required, which is effected by putting the liquid into a retort, to which is added a small quantity of muriate of lime to attract its moisture, connecting the beak of the retort with a receiver surrounded with ice or snow, and applying heat until the

* Journal of Science and the Arts, vol. iv. p. 361.

† Elements, Part i. p. 283.

‡ Philosophical Transactions for 1813, p. 171.

temperature is from 100° to 110° . The fluid distils over in a state of purity, and sulphur is left in the retort.

CCCCLVI. The sulphuret of carbon is a colourless and transparent liquid, possessing an acrid, pungent, and somewhat aromatic taste, and an exceedingly fœtid, nauseous odour. Its specific gravity is 1.272. One of its most characteristic properties is its prodigious power of refracting light. It is even superior to the diamond in this respect; it being stated by Dr. Wollaston as high as 1.645. Hence, when held between the eye and the light it exhibits the series of prismatic colours. At the temperature of $53^{\circ}.5$ its expansive energy is equivalent to 7.36 inches of mercury; it is vaporised between 105° and 110° , and does not freeze at -60° Fah. It is highly inflammable, takes fire at a temperature not above 700° , and burns with a bluish flame, at the same time emitting copious fumes of sulphurous acid.

Sulphuret of carbon is soluble in alcohol and ether, but insoluble in water.

When added to chloride of azote, the two liquids readily mix, and the latter loses its powers of explosion.

CCCCLVII. A singular compound was found by Mess. Berzelius and Marcet to be formed by the mutual action of sulphuret of carbon and nitro-muriatic acid. When they are mixed, they assume an orange red colour, and the odour of chloride of sulphur becomes perceptible. In the course of a week, a white crystalline solid forms upon the surface, which is dissolved by the liquid sulphuret so soon as it precipitates.

After about three weeks, the whole is converted into a solid substance resembling camphor. It has the odour of chloride of sulphur and oxide of osmium; its taste is acrid and acid, and it is volatile, melting in a gentle heat, and evaporating without residuum. It is insoluble in water, but is dissolved by alcohol and ether, and if water be present, changes vegetable blues to a red colour. From their experiments, Mess. Marcet and Berzelius have drawn the conclusion, that it is a compound of

Muriatic acid	- - - - -	48.74 parts
Sulphurous acid	- - - - -	29.63
Carbonic acid (and loss)	- - -	21.63
		<hr/>
		100.00

If this view of its composition be correct, and the experiments were conducted by distinguished chemists, it must be considered as a very extraordinary fact, that three acids, each of which in its uncombined state exists in the form of gas, should have an affinity for each other sufficiently powerful to counteract their tendency to elasticity, and enable them to assume the form of a solid.

CCCCLVIII. The sulphuret of carbon is highly volatile; it evaporates with great rapidity, and so much caloric is abstracted, that if a drop be placed upon the skin, it is benumbed, and might soon be frozen. This property suggested to Dr. Marcett, the practicability of obtaining by its evaporation, a great reduction of temperature; and he found that when the bulb of a delicate thermometer was covered with a piece of fine lint, moistened with a few drops of this liquid, and exposed to the air, the fluid sunk from 60° to 0 . When the bulb thus moistened was immediately introduced into the receiver of an air-pump, through a brass plate which was rendered airtight, and the air was exhausted, the temperature sunk with extraordinary rapidity, and in one or two minutes it had fallen from $+70^{\circ}$ to -70° , or even to -80° . A reduction of temperature from -65° to -70° may be easily produced in a pump which exhausts to $\frac{1}{4}$ of an inch of mercury; but when the vacuum is such as to support only $\frac{1}{8}$ of an inch, the spirit in the thermometer sinks in two minutes to -81° , or -82° . If a mercurial thermometer, or a tube containing mercury be substituted for the spirit, the fluid will of course be frozen; and the experiment was performed by Dr. Marcet. Care should be taken in prosecuting these experiments, not to work the pump very vigorously, for, in such cases, the heat evolved by

the condensed air rushing through the valve, will inflame the vapour of this substance with which it is mixed. This accident may be perceived by the sulphurous acid vapour which passes out of the barrels; but the inflammation has no other effect than that of injuring the valves. It takes place most frequently in receivers of large dimensions, and Dr. Marcet recommends that their capacity should not exceed 3 pints.*

From the results of the analytical experiments of Professor Berzelius and Dr. Marcett, sulphuret of carbon may be considered as a compound of 2 proportions of sulphur 30, and 1 proportion of carbon 5.7, and it will be represented by 35.7.

CCCCLIX. Sulphur is to be considered as a simple or undecomposed substance. Sir H. Davy, on submitting to the action of voltaic electricity a mass of Sicilian sulphur which was supposed to be perfectly dry, obtained from it 8 or 10 times its volume of sulphuretted hydrogen. The amount was thought to be too large to be furnished by the decomposition of any water which might have existed in it, and it was concluded, that hydrogen might be essential to the constitution of sulphur. This opinion he now considers as very doubtful, and the experiments of M. M. Gay-Lussac and Thenard have proved that dry sulphur does not contain hydrogen.

The uses of sulphur are numerous and important. In its simple state it forms a medicinal article, and it constitutes an essential ingredient in gun-powder, and the compositions for signal-lights. Combined with oxygen in the form of sulphurous and sulphuric acids, it is used in the arts of bleaching and of dyeing, and is a necessary agent in many of the operations of the chemist.

Of Cyanogen.

Carbon, it has been discovered, is capable of entering into combination with *Azote*, and of forming a very interesting compound.

* Phil. Trans. for 1813, Part ii p. 252.

CCCCCLX. When the salt called *prussiate of mercury*, in a perfectly neutral and dry state, is exposed to a degree of heat short of redness in a small retort connected with a mercurial apparatus, it is decomposed, a peculiar elastic fluid is disengaged in abundance, a quantity of mercury, together with a portion of the salt, is volatilized, and there remains a charry matter of the colour of soot, and as light as lamp-black. This gas was discovered, and its properties were described by M. Gay-Lussac in 1815. From the circumstances that it constitutes the basis of prussic acid, and that the most important compound of this acid is of a fine blue colour, he bestowed upon it the name of *Cyanogen*, from the Greek terms *κυανος*, blue; and *αγεννάω*, I produce.*

CCCCCLXI. Cyanogen is a permanently elastic, invisible fluid, of a strong, peculiar, and penetrating odour. Its specific gravity, compared with that of atmospheric air, is as 1.8064 to 1.0000, and with that of hydrogen as 24 to unity; and hence, 100 cubic inches, at a medium temperature, and under mean barometrical pressure, will weigh 55.95 grains. It bears a pretty high temperature without decomposition.

Water at the temperature of 68°, when agitated with it for some minutes, absorbs $4\frac{1}{2}$ times its volume of this gas. It is dissolved by sulphuric ether and oil of turpentine in as large quantities at least as by water, but pure alcohol or spirit of wine will condense no less than 23 times its bulk of cyanogen. The aqueous solution has a very sharp taste, it reddens tincture of litmus, and when heated, the gas is disengaged mixed with a little carbonic acid, and the blue colour of the vegetable tincture is restored.

Cyanogen is inflammable, and when kindled, it burns with a bluish flame mixed with purple; the results of its combustion are azote and carbonic acid. When mixed with oxygen in the proportion of 1 volume to $2\frac{1}{2}$ volumes, and fired in Volta's eudiometer, it produced a loud explosion, and a

* Memoir on Prussic acid, translated.—Thomson's Annals of Philosophy, vols. vii. and viii.

bluish flame similar to that of sulphur ; 100 parts of cyanogen being employed, the diminution amounted after the detonation to from 4 to 9 parts ; the residue treated with potash or barytes, was reduced from 195 to 200 parts, and consisted of carbonic acid ; and the remainder analyzed over water by hydrogen gave from 94 to 98 parts of azote, and the oxygen which the air contained previous to the last experiment, added to the oxygen in the carbonic acid, was equal to the $2\frac{1}{2}$ volumes of the gas employed. Neglecting the small differences, says M. Gay-Lussac, which prevent these numbers from having simple ratios to each other, we may admit that cyanogen contains a sufficient quantity of carbon to produce twice its volume of carbonic acid ; that is to say, 2 volumes of the vapour of carbon, and 1 volume of azote, condensed into a single volume.* Hence, it is a compound of 1 proportion of azote 13, and 2 proportions of carbon 11.4 ; and $11.4 : 13 :: 46.78 : 53.22$. The composition of cyanogen may therefore be stated as follows.

	Prop.	Atoms.	Weight.
Carbon - - -	2 - - -	2 - - -	46.78
Azote - - -	1 - - -	1 - - -	53.22
	<hr/> 3	<hr/> 3	<hr/> 100.00

And it may be represented by $11.4 + 13 = 24.4$.

CCCCLXII. Cyanogen is not altered when exposed to the heat of a spirit-lamp in contact with iodine, phosphorus, or sulphur ; nor does it suffer any change when mixed with hydrogen, and submitted to the action of the electric spark. Iron, when heated almost to whiteness and introduced into it, partly decomposes it, becomes covered with a slight coating of charcoal, and loses its malleability. The undecomposed portion of the gas is mixed with azote.

When the metallic basis of potash or potassium is introduced into it and gently heated, it takes fire, burns with flame, and the gas is speedily absorbed.

* Annals of Philosophy, vol. vii. p. 40.

Cyanogen combines with different bases, and forms compounds to which Gay-Lussac has given the name of *cyanurets*; the term *cyanides* would perhaps be more correct.

CCCCLXIII. M. Gay-Lussac did not observe any union to take place between cyanogen and iodine, phosphorus, or sulphur; but a mode has been since pointed out by Sir H. Davy, by which the combinations with these substances may probably be produced. It consists in heating bodies with prussiate of mercury; in this way the compounds above mentioned may be formed. The cyanide of iodine is a very curious body; it is volatile at a moderate heat, and on cooling collects in flocculi, adhering together like oxide of zinc formed by combustion, and it has a very acrid taste and pungent smell.*

Cyanogen rapidly decomposes the metallic carbonates at a dull red heat, and forms cyanides with the metals.

It acts upon ammoniacal gas so soon as they are brought into contact, but some hours are required to render the effect complete; a white vapour is first formed, which soon disappears, a considerable diminution in volume takes place, and the glass in which the mixture is made becomes opaque, in consequence of the deposition of a solid, brown coloured matter. This substance dissolves only in small proportion in water, and gives to it a dark colour. On mixing 90 parts of cyanogen with 227 parts of ammonia, they combine nearly in the proportion of 1 to $1\frac{1}{2}$.

Cyanogen and sulphuretted hydrogen slowly combine with each other, and a yellow substance is formed in fine needles which dissolves in water, but does not precipitate nitrate of lead, nor produce prussian blue; it is composed of 1 volume of cyanogen, and $1\frac{1}{2}$ volume of sulphuretted hydrogen.†

Although cyanogen does not combine with hydrogen by mixture, or even when exposed to the action of electricity, yet it has been amply demonstrated by M. Gay-Lussac that this

* Journal of Science and the Arts, vol. i. p. 283.

† Gay-Lussac.

compound exists in nature, and may be obtained from some of its combinations in an insulated form. To this compound he has given the name of Hydrocyanic acid ; it has long been known, and under the name of prussic acid has been the subject of much curious research and speculation. The exact knowledge now possessed of its composition is derived from the experiments of the distinguished French chemist, who demonstrated the nature of Cyanogen.

Hydro-cyanic, or Prussic acid.

CCCCLXIV. There is formed, for the purposes of the arts, a beautiful pigment, which is familiarly known by the name of *prussian blue*, and which was first manufactured at Berlin about a century ago. In general terms it is prepared by calcining a quantity of ox-blood or some animal substance with potash, dissolving the product in water, and adding the solution to a solution of a definite quantity of alum and green vitriol, a precipitate of a green colour is immediately formed, and this, when collected and washed with muriatic acid, is changed to a blue. The value of this article, and the circumstances connected with its formation, soon attracted the attention of the chemists, and efforts were made to discover and obtain in a separate state the substance which constituted the colouring matter of this rich pigment. It was ascertained by Macquer that prussian blue consisted of iron, and of a peculiar matter which might by certain processes be transferred to other substances, for example an alkali, and that when the latter was mixed with the solution of a salt of iron, the blue substance was re-produced. He also assigned a reason, the truth of which has since been established, for the change of colour effected by muriatic acid, and for the changes which take place when the colouring matter combined with an alkali is added to a salt of iron ; and he finally concluded that prussian blue was a compound of oxide of

iron with an inflammable substance which was converted by calcination into ammonia or volatile alkali and charcoal.

CCCCLXV. But little was known of the real nature and constitution of this colouring matter until the subject was taken up by the celebrated Swedish chemist, Mr. Scheele. After a variety of ingenious experiments, the results of which unfolded many of the properties of this substance, he succeeded in two important points, the first in separating it from its combination with iron in prussian blue ; and the second in forming it synthetically. Previous to his time, it had always been obtained in combination with, and through the medium of some substance of an animal nature ; but Scheele produced it by immersing pieces of sal ammoniac in a mixture of potash and charcoal, while in a state of fusion in a crucible, the mass when thrown into water producing a solution which had all the properties of a solution of potash which had been boiled on prussian blue. Hence he concluded, that the colouring matter of this pigment was composed of ammonia and charcoal ; and there is now no doubt that the elements of prussic acid are the same as those of ammonia, viz. azote and hydrogen, with charcoal or carbon. According to Dr. Thomson, the term prussic acid was first applied to this substance by Morveau.*

The subsequent researches of M. Berthollet developed still more the nature and properties of this acid. Instead of being a binary compound of carbon and ammonia, he considered it rather as a ternary compound of carbon, azote, and hydrogen, in which no oxygen could be detected. He succeeded also in forming a combination between this acid and oxy-muriatic gas, and gave to it the name of oxy-prussic acid. The subject was afterwards investigated by M. Curaudau, and by Mr. Proust ; and in 1806 Mr. Porrett executed a series of very ingenious and valuable experiments upon prussic acid and its compounds, and brought to light many curious facts connected with them. In 1815 the distinguish-

* System of Chemistry, vol. ii. p. 285, 5th ed.

ed French chemist, M. Gay-Lussac, undertook the investigation of this subject, and with his accustomed sagacity, completely demonstrated the composition of the prussic acid, the nature of its radical, and the kind of compounds which they respectively form with the different bases. To this radical, as has been stated, he gave the name of Cyanogen, and to its compound with hydrogen that of Hydro-cyanic acid.

CCCCI.XVI. This acid may be obtained, but not in a state of purity, by the process of Mr. Scheele; for all accurate experiments, it must be prepared by the method proposed by M. Gay-Lussac.

Mr. Scheele's consists in mixing together 10 parts of prussian blue in powder, 5 parts of red oxide of mercury, (or *red precipitate*,) and 30 parts of water, and boiling them in a glass flask until the red colour of the oxide disappears. The colour of the mixture gradually changes to a yellowish green. It is then to be poured upon a filtre, and to the solid residue are to be added 10 parts more of hot water. The liquid thus obtained is to be poured upon $2\frac{1}{2}$ parts of iron filings free from rust, and to the mixture is to be added 1 part of concentrated sulphuric acid with agitation. The iron rapidly dissolves, and metallic mercury is separated. When the action has ceased, the liquid is to be put into a tubulated retort connected with a small receiver kept cold by ice or cold water, and a moderate heat applied. The distillation is to be continued until about $\frac{1}{3}$ of the liquid has been vaporized. The fluid obtained is liquid prussic or hydrocyanic acid.

The method of M. Gay-Lussac yields this acid in a state of great purity. It is prepared from the salt which goes by the name of *prussiate of mercury*. To the beak of a tubulated retort containing the salt, is adapted a glass tube 2 feet in length, and $\frac{6}{10}$ of an inch in diameter. The first third of the tube nearest the retort is filled with small fragments of white marble to retain the muriatic acid that may come over, but which ought, if possible, to be prevented; the two other thirds contain fused muriate of lime, likewise in small pieces, in order

to attract the water which may be mixed with the prussic vapour, and to this end of the tube is adapted a small receiver, which must be surrounded with a frigorific mixture, or at least with ice, to prevent the escape of the acid in the form of vapour. Pure muriatic acid, but not in sufficient quantity completely to decompose the salt, is then poured into the retort, and a gentle heat is to be applied. The prussic acid is usually deposited upon the marble in the first portion of the tube, but by a moderate heat, it may be made to pass successively through the whole tube, and after being left for some time in contact with the muriate of lime, it may finally be driven into the receiver.

CCCCLXVII. Hydrocyanic acid thus obtained is a colourless and transparent liquid, possessing a strong smell, and affording a taste, at first cooling, then hot. Its odour has been compared with that of the peach-blossom. It is a violent poison. At the temperature of $44\frac{1}{2}^{\circ}$, its specific gravity is 0.7058, and at that of 64° , 0.6969. It is converted into vapour at $81\frac{1}{2}^{\circ}$, and forms ice at about 3° , and it affects sometimes the fibrous form of nitrate of ammonia. The cold which it produces, when converted into vapour, even at the temperature of 68° , is sufficient to congeal the remainder, and the phænomenon may be readily observed by putting a small drop at the end of a slip of paper or a glass rod. Though repeatedly rectified from pounded marble, it retains the power of feebly reddening paper stained blue with litmus.

The specific gravity of its vapour, compared with that of atmospheric air, is 0.9476, and this low density, when contrasted with its great volatility, furnishes a new proof, that the densities of vapours do not depend upon the boiling points of the liquids which produce them, but upon their particular nature.*

When this acid is kept in well-closed vessels, even though no air be present, it is sometimes decomposed in less than an

* Gay-Lussac.—Memoir on Prussic acid.

hour. M. Gay-Lussac remarks, that he has often kept it 15 days without alteration ; but it can seldom be preserved longer without exhibiting signs of decomposition. It commences by assuming a reddish brown colour, which continues to deepen, and gradually deposits a considerable quantity of carbonaceous matter, which gives a deep colour both to water and acids, and exhales a strong odour of ammonia. If the bottle be not closely stopped, nothing remains but a dry charry mass.

Iodine and phosphorus suffer no change when volatilized in contact with hydrocyanic vapour, but sulphur rapidly absorbs it, and a substance is formed, apparently of the same nature as that which is produced by the reciprocal action of cyanogen and sulphuretted hydrogen.

When the vapour of this acid is transmitted through a porcelain tube heated to redness, it is decomposed, the airs obtained are hydrogen, a little azote, and cyanogen mixed with a considerable portion of the acid undecomposed, and the inside of the tube is covered with a slight coating of charcoal. Hydrocyanic acid combines with some of the salifiable bases, and forms salts called *hydrocyanates* ; in other cases, hydrogen is disengaged, and the results are *cyanides*.

When this acid is electrified in the circuit of a voltaic battery, from wires of platina, hydrogen is given off at the negative pole, and a compound of cyanogen and platina formed at the positive pole.* M. Gay-Lussac found that by common electricity, its vapour was partially decomposed, and that a small portion of carbon was separated.

CCCCLXVIII. When the vapour of hydrocyanic acid is mixed with oxygen, and inflamed by the electric spark, the combustion is lively, and accompanied with a flame of a bluish white colour. For complete saturation, 100 measures of the acid require 125 of oxygen, and the results are 100 of carbonic acid mixed with 50 of azote. Now, as in the formation of carbonic acid, the volume is unchanged, 100 measures of the

* Sir H. Davy.—Journal of the Royal Institution, vol. i. p. 288.

oxygen were consumed in combining with the carbon, the azote was disengaged, and the remaining 25 measures of oxygen must have combined with 50 of hydrogen to form water. That hydrogen in this proportion exists as a component part in hydrocyanic acid was likewise proved by Gay-Lussac by the action of potassium upon the vapour; for in this case, cyanide of potassium was formed, and 50 measures of hydrogen, when 100 of prussic vapour were employed, were disengaged. Hence, it appears that hydrocyanic acid is a compound of

One volume of vapour of carbon,
Half a volume of azote,
Half a volume of hydrogen,

or what perhaps will appear most probable, it may be considered as a compound of equal volumes of cyanogen and hydrogen united without condensation. The proportions, as stated by Gay-Lussac, are

Carbon	-	-	-	-	-	-	-	44.59
Azote	-	-	-	-	-	-	-	51.71
Hydrogen	-	-	-	-	-	-	-	3.90
								<hr/>
								100.00

Upon the supposition that it is a binary compound of cyanogen and hydrogen, its representative number will be $24.4 + 1 = 25.4$.

Cyanogen is capable of combining with chlorine, and of forming a peculiar compound, which M. Berthollet designated by the name of oxy-prussic acid. M. Gay-Lussac calls it

Chloro-cyanic acid.

CCCCLXIX. In order to form this acid, a current of chlorine was passed through hydrocyanic acid until it was capable of destroying the colour of a diluted solution of indi-

go in sulphuric acid, and the excess of chlorine was withdrawn by agitating the liquid with mercury. To separate the pure chloro-cyanic acid, the liquid was put into a tube, two thirds of which were filled with mercury, and the mouth of the vessel was inverted in a bason of mercury; the apparatus was then put under the receiver of an air-pump, and the air was exhausted, elastic fluid was generated, which pressed the whole of the liquid without the jar, so that when the air was re-admitted, the vapour of chloro-cyanic acid was condensed, and the mercury rose in the jar.

Chloro-cyanic acid is a colourless and transparent liquid, of a peculiarly strong irritating smell, affecting the pituitary membrane, and producing tears like ammonia. It reddens vegetable blues, is not inflammable, and does not detonate when mixed with twice its bulk of oxygen or hydrogen. Its density, as determined by calculation, is 2.111. Its aqueous solution does not precipitate nitrate of silver, nor barytic water. The alkalies absorb it rapidly, but an excess of them is necessary to destroy its odour. If an acid be then added, a strong effervescence of carbonic acid is produced, and the odour of chloro-cyanic acid is no longer perceived; and when an excess of lime is added to the acid solution, ammonia is disengaged in abundance.

Its combustion with oxygen takes place only when a little hydrogen has been previously added. It is very lively, producing a bluish white flame, accompanied with a very dense white vapour, the odour of which has something nitrous, while its taste is mercurial.

From the experiments of M. Gay-Lussac, it is composed of

One volume of the vapour of carbon,
Half a volume of azote,
Half a volume of chlorine,

or of

One volume of cyanogen,
One volume of chlorine.

so that the density of chloro-cyanic acid is the mean of the densities of cyanogen and chlorine, or 2.111. It may be represented by $33.5 + 24.4 = 57.9$.

Chloro-cyanic acid is characterized by its property of precipitating iron from its solutions of a green colour. It was discovered by Berthollet, and in order to produce it, chloro-cyanic acid, according to Gay-Lussac, must be first added to the solution of iron, then a little potash, and the green precipitate is formed upon the subsequent addition of an acid.

A weak and somewhat impure solution of chloro-cyanic acid may be easily formed by filling a phial with solution of hydro-cyanic acid, and forcing out half the liquid by a stream of chlorine, the vessel is then agitated until the gas is absorbed. When thus prepared, it gives out a very strong odour of chloro-cyanic acid.

CCCCCLXX. Hydro-cyanic or prussic acid is found to exist apparently ready formed in some vegetables. The leaves of one species of laurel, the *prunus lauro cerasus* of botanists, yield it by distillation with water, and the weak solution, under the name of laurel-water, has been long known as an active poison. It may be procured also from fruit of the *amygdalus communis*, and the *prunus avium*, and from the kernels, leaves, and blossoms of the *amygdalus persica*, or peach. The prussic acid has likewise been found in the barks of some other plants. The action of the hydro-cyanic acid upon the animal economy is wonderful; it operates as a deadly poison, and its action is more virulent than that of any of the substances ranked in this class, for even in minute quantity it produces in its pure and concentrated state, instant death. This has been proved in the most striking manner among others by M. Magendie. The extremity of a glass tube was dipped into a phial containing a few drops of pure hydro-cyanic acid, prepared according to the method of Gay-Lussac, and introduced quickly into the mouth of a vigorous dog; the tube had scarcely touched the tongue of the animal when he made two or three deep and rapid inspirations, and instantly fell dead.

The irritability of the muscular fibre was destroyed. In another experiment, some atoms of the acid having been applied to the eye of a dog, the effects were almost as suddenly produced as those just related. A drop of the acid diluted with four drops of alcohol, having been injected into the jugular vein of a third dog, he fell dead as if he had been shot, or had sustained a shock of lightning. In a word, says M. Magendie, the pure prussic acid is without doubt of all known poisons the most active and the most speedily fatal. The powerful deleterious influence which it exhibits, sanctions the belief in the accounts which have been given by historians of the culpable talent of Locusta, and renders less extraordinary the sudden poisonings, so common in the annals of Italy. It will be seen, therefore, that too much care cannot be taken to avoid breathing its vapour, during the process employed for its formation. It acts upon warm-blooded animals by destroying the sensibility and contractility of the muscles, and death is produced with a rapidity, proportional to the quickness of the circulation, and the extent of the respiratory organs.*

Hydrocyanic or prussic acid has been employed in the practice of medicine principally as an anti-spasmodic. In preparing it for this purpose it should always be obtained by the process of Scheele, as in that state, it is much diluted with water, and there is little or no danger to be apprehended by the operator.

Sulphuretted Chyazic, or Sulphocyanic acid.

CCCCLXXI. Between the years 1809 and 1814, Mr. Porrett submitted prussic acid and its compounds to a rigid examination, and his curious and interesting experiments terminated in the discovery of two acids, which differed in properties both from the hydrocyanic and the chloro-cyanic acids. To these bodies he applied the rather singular names of sulphu-

* Annals de Chimie et de Physique, t. vi. p. 347.

retted and ferruretted chyazic acids, the last term being compounded of the first letter of carbon, the first syllables of hydrogen and azote, with the usual termination which designates an acid.* They were considered by him as compounds of sulphur and iron with hydro-cyanic acid ; but since the researches of M. Gay-Lussac into this subject, they may rather be regarded as combinations of cyanogen, the radical of the prussic acid, respectively with sulphur and iron, and hence the terms sulphocyanic and ferrocyanic, which have been adopted by Dr. Thomson, may be thought preferable.†

CCCCCLXXII. It has been already stated, that when M. Gay-Lussac mingled together cyanogen and sulphuretted hydrogen, a peculiar compound was formed which existed in the state of a solid. It is not said whether hydrogen gas was disengaged ; if it were, the compound must have been similar in composition to the sulphuretted chyazic acid of Mr. Porrett.

The process employed by the last chemist to obtain this substance was long and complicated. Three or four parts of prussian blue, added in small quantities at a time, were boiled for some time in a solution of one part of sulphuret of potash in water ; a transparent, colourless, and neutral liquid was obtained, to which after filtration was added sulphuric acid in sufficient quantity to give it decidedly acid properties. The liquid was kept for a short time at a temperature near to its boiling point, and afterwards allowed to cool. On the addition of a little finely powdered black oxide of manganese, the solution acquired a fine crimson colour ; and after filtration it was decomposed by pouring into it a solution of 2 parts of *blue vitriol* and three parts of green sulphate of iron in water, until the crimson colour disappeared. A white precipitate, composed of sulpho-cyanic acid and oxide of copper, was formed, the former of which was transferred to potash when boiled in its solution. To the filtered liquid was added sulphu-

* Philosophical Transactions for 1814, p. 527.

† System of Chemistry, vol. ii. pp. 290 and 295, 5th ed.

ric acid in excess, and by subsequent distillation the sulpho-cyanic acid passed into the receiver mixed with a little sulphur and sulphuric acid, from which it was freed by saturating the liquid by carbonate of barytes, and decomposing the compound by the cautious addition of sulphuric acid.

Obtained in this way, sulpho-cyanic acid is a transparent and colourless liquid, of a strong odour, which has been compared with that of acetic acid. Its specific gravity, according to Mr. Porrett, is 1.022. When exposed to a boiling heat or when distilled, it leaves a small quantity of sulphur; whence it appears, that a portion of it is decomposed, and the decomposition may be rendered complete by repetitions of the same operation. It is capable when aided by heat of dissolving sulphur, but the solution is not permanent, for as its temperature falls, that substance is again deposited. It combines with the salifiable bases and forms for the most part very soluble and deliquescent, crystallizable salts, which are called *sulpho-cyanates*.

The presence of sulphur in this compound may be ascertained by mixing it with solution of nitrate of lead; no action takes place between them, but on adding a little nitric acid, and applying a gentle heat, an effervescence ensues, nitrous gas is disengaged, and sulphate of lead precipitated. In this experiment the sulphur becomes oxygenized at the expense of the nitric acid, and is separated in combination with the oxide of lead in the form of sulphuric acid.

Mr. Porrett conceives that this acid contains one third of its weight of the elements of prussic acid, and two thirds of its weight of sulphur. By Dr. Thomson it is inferred to be a compound of 1 atom of cyanogen, and 3 atoms of sulphur.

Ferruretted or Ferrocyanic acid.

CCCCLXXIII. All the salts which were formerly called triple prussiates, and which are formed by the decomposition of prussian blue by the salifiable bases, contain, according to

Mr. Porrett, this acid in combination. It may be prepared by dissolving *triple prussiate of barytes* in cold water, and adding to it as much sulphuric acid as is just sufficient to neutralize the base. The whole is suffered to remain at rest for a time, the sulphate of barytes thus formed precipitates, and the clear liquid is decanted. It constitutes an aqueous solution of ferro-cyanic acid.

It has a pale lemon colour, and is destitute of odour. Exposed to a gentle heat, or to a strong light, it is decomposed, prussic acid is formed, together with the white triple prussiate of iron, which soon changes to prussian blue. Its affinities are stronger than those of acetic acid, and it separates that acid from all its combinations. It combines with different bases and forms salts, which were formerly called *triple prussiates*, but which have now received the name of *ferro-cyanates*. According to Mr. Porrett, it expels all acids from soluble combinations, when it is capable of forming insoluble salts with the bases to which they were previously united.

When the triple prussiate of soda in solution was exposed to the action of voltaic electricity, its acid was separated at the positive pole, hydro-cyanic acid was evolved, and triple prussiate of iron deposited.

According to Mr. Porrett, the acid in ferruretted chyzate of potash consists of 30.40 parts of prussic acid, and 17.26 of black oxide of iron. It is very doubtful, however, whether it consist of this oxide united with the elements of hydro-cyanic acid. From the phenomena observed by M. Gay-Lussac, during the action of prussic acid upon the metals, it appears that the salts, which were considered as prussiates, are in most instances compounds of cyanogen; and the ferruretted chyzic acid, instead of containing hydrogen, may be regarded either as a cyanide of iron, or as a triple compound of cyanogen, iron, and oxygen. The composition of the acid agrees best with the theory of definite proportions, in considering it as a cyanide of iron; but upon this assumption, it would be difficult to account for the fact, that it appears to perform the function of an acid.

CHAPTER III.

OF COMBUSTION.

CCCCCLXXIV. This is the most important, as well as the most beautiful of all the processes which may be directly referred to chemical action, and were it not a subject of familiar observation, would excite the admiration of the most ignorant beholder. When the importance of *fire*, and the mystery which hangs over its real nature are considered, it is not surprising that combustion should have claimed the attention of men, from the first dawn of theoretical chemistry, nor that the principles of the science itself should have been deduced from investigations made into its phenomena. We find in fact, that with the gradual improvement in Chemistry, the hypotheses which had been formed to account for the effects of this process, experienced successive revolutions, that even at this period, when the art of refined analysis has afforded us some knowledge of the nature of the materials, and the products of this action, many of the circumstances connected with it require to be explained upon hypothetical data, and that much still remains to be known, before the philosophy of combustion can be considered as founded upon a permanent and unchangeable basis.

Bodies viewed in relation to this process may be divided into *Combustible* and *Incombustible*. When a substance of the latter description is exposed to heat, its temperature rises in proportion, and supposing its form to be permanent, it may become ignited to whiteness, but as the heat is withdrawn it returns to its former state, apparently unchanged in its properties and relations. On the contrary, when the temperature of a combustible body, while exposed to the air, rises to a certain degree, it suddenly experiences a great elevation, and the inflammable matter acquires the property of emitting rays of light and caloric. During this period, it undergoes a great-

er or less change in its form and properties, and it is this change, and the radiation of luminous and calorific rays which constitute the phenomena of combustion. The questions, then, immediately present themselves, what is the difference between these two classes of bodies, what are the causes of the modifications which the latter undergo, and what the sources of the light and heat which they radiate? In order to answer these queries in a satisfactory manner, it will be necessary to review the opinions which have been proposed upon these subjects, and to state the different hypotheses which have prevailed at different epochs in the history of Chemistry.

CCCCCLXXV. The first approximation towards a theory of combustion was made by Hooke, an English philosopher of celebrity, who published his work in 1665. He conceived that the air, in which we live, move, and breathe, might be considered as the *menstruum*, or universal solvent of all sulphureous bodies;* this property residing not in the whole of the air, but in one part of it, which is analogous to, if not the same as that which is fixed in a solid state in nitre. Bodies require to be heated to a certain degree before they can be dissolved, but while the solution is taking place, great heat, and that which we call fire, is produced, and the action is so violent as to communicate to the surrounding air, the pulse or vibration of light. As there is one part dissoluble by the air, so there are others which are not soluble, but in consequence of the violent motions which accompany these actions, they become mixed with the air, forming coagula, or precipitates which, when the process ceases, are deposited in the form of *soot*; and when the parts are neither dissoluble, nor volatile, they remain behind in the state of *ashes*. As salt-petre abounds with these dissolvent particles, a small quantity of it will dissolve a great sulphureous body, but the particles in the air, being comparatively few, a small quantity of this elastic fluid is

* The word *sulphureous* appears to have been applied by the earlier chemists as a general term to all combustible substances, and it was used in the same sense by Sir Isaac Newton.

quickly saturated, and hence arises the necessity of supplying a current of fresh air to burning bodies, in order that the quantity applied may compensate for the small proportion of the menstruum existing in the atmosphere. "The shining, transient body, which we call *flame*, is nothing else but a mixture of air, and volatile sulphureous parts of dissoluble or combustible bodies."*

A part of this hypothesis was embraced and extended by Mayow, whose works were published about ten years after the *Micrographia* of Dr. Hooke. To the menstruum of the latter he gave the name of Nitro-aërial spirit, and endeavoured to show that although it is uninflamable, its presence is essential to combustion, that it is contained in nitre, and gives acid properties to sulphur, that when some of the metals are exposed to heat, they imbibe this spirit and increase in weight, that it is absorbed by animals during the process of respiration, and that the heat and light which are manifested, result from the violent motions occasioned by the reciprocal action of the particles of this nitro-aërial spirit, and those of combustible bodies.†

It is remarkable how near this view of the nature of combustion corresponds with the modern doctrines upon this subject. Had these speculations been followed up, and been presented to the world in a simple experimental form, the greater part, if not the whole of the theory, which marked the era of 1772—80, would have been developed more than a century ago. Hooke affirms that his opinions were formed "from an infinite of observations and experiments;" he promised to renew the subject in a separate work, but I do not know that the promise was fulfilled. With regard to Mayow, his views were not clearly unfolded; his useful observations were enveloped in a mass of absurdities, which obscured their real value, and probably prevented them from

* *Micrographia*, p. 103—105.

† Thomson's *System of Chemistry*, vol. i. p. 134, 5th ed. Brande's *History of Chemistry*.

making any permanent impression upon the minds of his contemporaries, or immediate successors ; and in fact the hypotheses of these sagacious men were disregarded or forgotten, so soon as Stahl proposed the refined and consistent theory of Phlogiston.

CCCCCLXXVI. Beccher, a German chemist of reputation, advanced in his works the original hypothesis, that there existed in nature but one simple elementary body, to which he gave the name of earth. This he supposed to exist in three different states, forming the vitrescible, the inflammable, and the metallic earths, and to produce, by their union, the different compounds which constitute the globe. There was little, however, to be said in favour of this opinion, and it was considered rather as the effort of an ingenious but speculative mind, than as a legitimate hypothesis. It was reserved for Ernest Stahl, of Vienna, the pupil of Beccher, to form a simple, satisfactory, and beautiful theory from the bold and original thought of his master. His works were printed between the years 1723 and 1732, and with his name is joined the proud distinction of having given, for more than half a century, the laws of this science to all the chemists of Europe.

CCCCCLXXVII. It was inferred by him that there was present in all combustible bodies an highly attenuated, ethereal matter, to which he gave the name of Phlogiston. He supposed that during combustion this principle was in the act of disengagement, that when completely evolved the body was burnt, and in that state incapable of going through the same process a second time ; that phlogiston might be slowly disengaged without giving rise to the phenomena of active inflammation, or transferred from one body to another, the former losing and the latter acquiring the property of combustibility ; and that the light and heat which were manifested in this process were the consequences of the violent motions of this phlogiston, as it passed from the inflamed body. Such were the principles of the theory of phlogiston, and they were deduced from such a multitude of facts, and supported by so

many apparently convincing illustrations, that it obtained unlimited belief, and was publickly taught as the basis in fact of the science of chemistry.

Some of the most obvious facts, from which these conclusions were derived, were the following. Charcoal when inflamed burns almost entirely away, and therefore consists of phlogiston nearly in a state of purity; but when sulphur is consumed, the product is a strong acid, which must be conceived to be sulphur deprived of phlogiston. This ethereal matter then exists in much larger proportion in the former solid, than in the latter. Some of the metals, likewise, when their temperature is raised, undergo combustion, and when the process is concluded, they appear in the form of a calx, or earthy body; hence the metals are to be regarded as composed of bases united with phlogiston, and when the phlogiston is dissipated, these bases assume the form of calces. But if the products of combustion be considered as bodies deprived of this principle, they ought to be restored to their original forms whenever the phlogiston can again be added to them; accordingly it was found, that when the acid, resulting from the burning of sulphur, was heated in contact with charcoal, it disappeared, and sulphur was produced. Antimony, when heated in contact with the air, was changed into a calx, but when this calx was mixed with charcoal, and exposed to a high temperature, the metal re-assumed its original qualities. From a multitude of experiments similar to those which have just been mentioned, the existence of phlogiston appeared to be demonstrated to the satisfaction of chemists, and no doubt was entertained of its reality, until after the discovery of some of the elastic fluids by Priestley, of the composition of water by Cavendish, and of the nature of metallic calces by Bayen and Lavoisier.

CCCCLXXVIII. The theory of Stahl appeared adequate to the explanation of the phænomena of common combustion, in which some of the products escape observation, and it seems to have been adopted without any minute examination into its

merits ; but after many years, when chemists were to be satisfied only by demonstration, the question naturally arose, what is phlogiston ? No satisfactory answer could be returned. The existence of this principle was problematical, it had never been obtained in a separate state, and the belief in its reality was continued, rather from the ease with which it enabled chemists to explain some of the most important phænomena of the science, than from any precise knowledge of its nature, or any actual experience of its properties. If the foundation of the theory was thus doubtful, the doubt was not removed in examining more critically the facts, to which it was considered to be most applicable. Stahl had altogether overlooked the important fact, stated long before his time by the French physician Rey, and afterwards by Mayow, that metallic calces are heavier than the metals from which they are formed ; a fact entirely irreconcilable with his theory ; for though it might be supposed, that in consequence of the levity of phlogiston, the weight of bodies would not be affected by its disengagement, yet it was little less than absurd to consider it as the principle of levity, and as rendering the substances with which it was combined, specifically lighter than without it. The reciprocal influence of atmospheric air, and combustible bodies, however, had been so ingeniously stated, that it was difficult to develope the true nature of this action. When substances were consumed in common air, the phlogiston was supposed to pass from the former to the latter, the air became saturated with this principle, or phlogisticated, and fresh portions were required to continue the combustion.

It was obvious, that if metallic calces were to be considered as peculiar bases, which were to be obtained only by the evolution of their phlogiston, they would require, in order to be again converted into metals, to be brought into contact with some substance which contained it, and from which it might be transferred ; but if these earthy bodies could be reduced to metals, without the agency of phlogiston, it was to be inferred either that they were not calces, or if they were, that the doc-

trine of Stahl was incapable of giving any satisfactory reason for the reduction. Proceeding upon these principles, Bayen, after a series of laborious experiments, succeeded in converting some of the calces into metals by the sole influence of heat. Hence, as no substance was present, which could furnish phlogiston, and further, as the calces during this change gave out a quantity of dephlogisticated air, the conclusion was unavoidable, that metals, which are combustible bodies, do not contain phlogiston.

CCCCLXXIX. If, then, the opinions of Stahl were entitled to adoption, it was necessary to give to phlogiston an actual existence, and to account for the increase of weight in the products of combustion. The attempt was made by Mr. Kirwan, and in his work *On Phlogiston and the Constitution of Acids*, he endeavoured with much ingenuity to show, that inflammable air, or what is now called hydrogen, might be considered as the phlogiston of Stahl, that it exists as a constituent part in all combustible bodies, that it is evolved from them when they are exposed to heat, combines with a portion of the air, and the two then unite with the burning body, and increase its weight. This hypothesis was partly founded upon the facts discovered by Dr. Priestley. This celebrated man had ascertained that some of the metals, on exposure to a high degree of heat, produced hydrogen gas; and, what perhaps was at that time more important to the theory, that when this gas was heated with the metallic calces, the air disappeared, and the metals were restored. From facts like these, it might be concluded, that hydrogen was a constituent part of the metals, and capable of reducing their calces. Dr. Priestley laboured with zeal in the cause of phlogiston, and his experiments were varied, and multiplied to a great extent to demonstrate its identity with hydrogen; but the arguments just mentioned lost all their force, after the discovery was made by Mr. Cavendish, that the product of the combination of hydrogen with oxygen, was water. In proportion as the nature of metallic calces, the composition of the atmosphere,

and the constitution of water were unfolded, the theory of phlogiston lost its importance, and a few years after the refutation of Mr. Kirwan's arguments by the French chemists, the theory of combustion experienced a complete revolution, and was apparently fixed upon the unyielding basis of observation, experiment, and pure induction.

CCCCCLXXX. This revolution, which overturned the whole system of Stahl, took place between the years 1772 and 1777, and its author was the celebrated and unfortunate Lavoisier. No man, perhaps, was better calculated to create and give currency to a new theory. Enjoying all the influence which high political distinction, a splendid fortune, and the reputation for uncommon talents, can bestow; trained for the severer studies by an early and judicious education; well acquainted with the science of his age; and already distinguished as a zealous cultivator of physical philosophy; he applied the methods of the exact sciences to chemistry, he performed a series of laborious experiments, and deduced his principles from them with the cautious spirit of the geometrician. He distinctly claims this theory as his own, for in his observations upon a paper deposited in the French Academy in 1772, after stating some of the facts upon which it was founded, he remarks, "*Cette théorie n'est donc pas, comme je l'entend dire, la théorie des Chimistes François; elle est la mienne, et c'est une propriété que je réclame auprès de mes contemporains, et de la postérité.*"*

The important facts upon which this doctrine was founded had been already discovered. The existence of oxygen was proved by the experiments of Priestley, Scheele, and Lavoisier himself, the nature of metallic calces or oxides was unfolded by this great chemist and Bayen, and the relations of caloric to different forms of matter were before this period pointed out by Dr. Black. These discoveries, when taken in connexion with the facts opposed to the hypothesis of phlogiston, furnished materials, which, combined by the sagacious

* Brande's History of Chemistry.—Encyclop. Britannica, Supplement.
VOL. I. 61

mind of Lavoisier, and extended by his laborious researches, were formed into a system, that united the different parts of chemistry, and gave to it the form of a complete and exact science.

The basis of this theory is founded upon the phenomena exhibited by the reciprocal action of oxygen and combustible bodies, and the nature or composition of the products. The principles may be stated in the following propositions.

1. Combustion will not proceed without the presence of oxygen, either in the elastic form, or, when combined with other bodies, in that of a liquid, or a solid.

When a lighted candle is introduced into hydrogen, azote, or ammonia, it is immediately extinguished; if plunged into a definite portion of atmospheric air, it burns but a limited time; the combustion is more vivid in nitrous oxide, and intensely brilliant in pure oxygen gas. If the metal called potassium be put into water, a flame of a beautiful rose colour is immediately formed, the solid gradually disappears, and the remaining liquid is a solution of potash. The water then must be decomposed, and its oxygen transferred to the potassium with such rapidity, as to give rise to the phenomena of active combustion. This process may even be observed in the mixture of solid bodies, one of which is combustible, while the other contains oxygen; hence, if sulphur and nitre be blended together, and be exposed to a certain degree of heat, inflammation will take place, and a peculiar compound be formed. The same circumstances will be observed, if powdered charcoal be projected into a vessel containing melted nitre.

But if oxygen be required in all cases of combustion, it is reasonable to suppose that this process will proceed with a rapidity proportional to its purity; and this in fact is the case. Inflammable bodies burn in atmospheric air without tumult or commotion, and there are some of this class, which in this state can be ignited only with great difficulty, but when introduced in an inflamed state into pure oxygen, they

readily take fire, and consume with great brilliancy. Sulphur burns in the open air with a pale blue flame scarcely visible in the day, but in oxygen gas, the flame is not only greatly enlarged, but it assumes a beautiful violet, which, after a while, changes to a rose colour; and phosphorus, which gives out a bright light, while consuming even in common air, burns in pure oxygen with such vehemence, and a flame so intensely white, that it is painful to the eye. It appears then that the degree of combustion is in proportion to the purity of the oxygen, and that the temperature of bodies while consuming in this gas is much higher than in atmospheric air. Hence it happens that some bodies may be made to burn with ease in the former, which we might in vain attempt in the latter. Iron, for example, when heated strongly, and introduced into oxygen gas, becomes intensely ignited, gives out a brilliant light, and vivid sparks are occasionally projected from the inflamed mass. All the facts which we have mentioned, and a multitude of others of the same nature, sufficiently prove, that the presence of oxygen is essential to combustion, and that this process will proceed with a rapidity and brilliancy proportional to its purity.

2. In all cases of combustion, oxygen disappears.

When charcoal or sulphur is consumed in a close vessel filled with an elastic fluid consisting of, or containing oxygen, it will be found, after the experiment is concluded, that the properties of the residual air are very different, and that the presence of oxygen in it cannot be detected by common means. That oxygen gas disappears during this process is also proved by placing a lighted candle under a large receiver filled with atmospheric air, and standing over water; the light will gradually grow fainter, in a certain time it will be extinguished, and when the temperature of the apparatus has fallen to that of the surrounding air, the water will be found to have risen into the receiver, and to have occupied about $\frac{1}{5}$ of its capacity. The air which remains exhibits none of the properties of oxygen. This general fact is completely

illustrated by the combustion of iron. Place a roll of fine iron wire, with a small piece of cotton which has been soaked in melted sulphur attached to it, in a cup resting upon the surface of mercury, and bring a receiver, having an orifice at the top which is closed, over it, the lower edge being immersed in the metallic fluid, heat the end of an iron wire red hot, introduce it into the vessel as quickly as possible so as to bring it in contact with the cotton, then withdraw it and close the receiver, the combustion of the sulphur will cause the iron to take fire, it will burn brilliantly, and the mercury will gradually rise in the vessel.

3. Combustible bodies during this process increase in weight, and the weights lost by the air, and gained by such bodies, are precisely equal.

If the weight of the iron in the experiment above-mentioned have been previously determined, it will be found, after combustion, to weigh more than before; and as the weight of a definite portion of oxygen gas has been accurately ascertained, it will be easy to calculate the weight of the cubic inches which have disappeared. When this was done by Lavoisier, he proved, that the weights lost by the oxygen and gained by the iron were equal, and consequently that the increase of weight in the metal was to be ascribed solely to the oxygen with which it had entered into combination. This fact was also demonstrated by what may be termed the slow combustion of mercury. When a portion of this metal was exposed to heat in a glass vessel of a known capacity, and filled with atmospheric air, there gradually formed upon its surface a red crystallized substance which continued to increase in quantity for a certain period, when it ceased to be produced. Upon examination, the air of the vessel was found diminished in bulk about 8 cubic inches, the red matter weighed 45 grains, and when exposed to heat $41\frac{1}{2}$ grains of mercury were formed, and nearly 8 cubic inches of an elastic fluid, possessing all the characters of oxygen, passed into the receiver; this air, when mingled with the residual air

in the vessel, restored it to its original volume and properties, or in other words, re-composed atmospheric air. The weight of the oxygen, therefore, which had disappeared during the process, was just equal to the weight gained by $41\frac{1}{2}$ grains of mercury in their conversion into the red matter, and this experiment together with others conducted on a similar principle sufficiently demonstrated, not only that the metals during their change into calces increase in weight, but also that this augmentation is owing to the absorption of oxygen. Metallic calces then are not metals deprived of phlogiston, but these bodies combined with oxygen, and in the new nomenclature, which was soon after promulgated by Lavoisier and his associates, their composition was designated by applying to them the expressive name of *Oxides*.

It is not always the case, however, that this correspondence between the weight lost by the air and gained by the combustible body can be accurately ascertained; and when compounded bodies, such as wood or other articles commonly employed as fuel, are consumed, a small proportion only of the whole mass remains behind in the form of ashes; yet if all the volatile substances disengaged by the heat were to be preserved, and all the aerial products of the combustion collected, there can be no doubt that the weight of these bodies, added to that of the solid residue, would be greater than the weight of the mass before the experiment, and likewise that this increase would correspond precisely with that of the oxygen combined.

4. The oxygen which disappears in combustion, and is fixed in combination with the inflammable body, may, by certain processes, be again obtained, and the combustibility of the base will be restored.

When hydrogen and oxygen, in certain proportions, are burned, the product is water, and if the liquid thus formed be exposed to the action of voltaic electricity, it will be resolved into two elastic fluids which may be proved to consist of oxygen and hydrogen in the same proportions, and if the

mixture be inflamed, it re-produces water. Mercury on exposure to heat, attracts oxygen and increases in weight, but if the compound be exposed to a temperature somewhat higher than that necessary for its formation, it will be decomposed, the mercury will be reduced to its original weight, and the oxygen obtained will be equal to the difference in weight between the metallic mercury, and the compound which had been decomposed. Hence the facts, which were brought forward by Stahl to demonstrate the truth of his theory, may be applied with more success to substantiate the principles of Lavoisier. Charcoal was conceived to be phlogiston nearly pure, because when inflamed it burned almost entirely away; and because when heated with the products of combustion, it disappeared, but at the same time restored to the bodies with which it was mixed their power of inflaming. But it will now be seen that it owes its inflammability to its affinity for oxygen, and that when heated sufficiently in contact with sulphuric acid, it produces sulphur, not by communicating phlogiston, but by abstracting oxygen; for if the elastic fluids formed in this process be collected, one of the products will be found to be carbonic acid, and this body was demonstrated by Lavoisier himself to be composed of carbon, the inflammable basis of charcoal, and oxygen. Now carbonic acid when mixed with an equal volume of hydrogen, and acted upon by electricity, produces water and carbonic oxide; and if this last gas be transmitted over the surface of ignited porcelain, after having been mingled with its own bulk of hydrogen, the products will be carbon and water. Hence we see, that oxygen is first transferred from sulphur, which thus resumes its combustible property, to charcoal; and that it is attracted from charcoal by hydrogen, the products of this union in both cases being unflammable.

CCCCCLXXXI. But although the important general law, that in every case of combustion, oxygen combines with the burning body, was, by the fortunate researches of Lavoisier, established by the most rigorous induction, the theory was

not completed. The origin of the heat and light, which are developed in this process, remained to be accounted for, and for this purpose, he called to his aid the discoveries of Dr. Black upon the subject of heat. He inferred that oxygen gas consisted of a base, chemically combined with a certain quantity of caloric, and to which it owed its elastic form. A combustible body, says he, is one which has the property of decomposing vital air, which has a greater affinity for its base, than exists between this base and the matter of heat, so that combustion is nothing more than the separation of oxygen from this matter of heat to enter into a new combination. Hence, when sulphur, phosphorus, or carbon, is burned, it is stated by him to be in consequence of the stronger elective affinity possessed by the combustible for oxygen, than for caloric, it attracts the base of the gas, from the caloric, and the latter being disengaged spreads itself over surrounding bodies.* That the oxygen gas is sufficient to supply all the caloric which is manifested during combustion, he infers from experiments which were made with the calorimeter. Thus, 1 pound of phosphorus requires for complete combustion, 1 pound 8 ounces of oxygen gas, and the quantity of caloric given out is sufficient to melt 100 pounds of ice; a pound of charcoal absorbs during combustion 2.5714 pounds of oxygen, and converts 96.5 pounds of ice into water; and the same weight of hydrogen combines with 5.66 pounds of oxygen, and the caloric communicated to ice is sufficient to change 295.58 pounds into water. But the proportions in which the three substances combine with oxygen have been found, from more recent researches, to differ from those stated above, and it may be observed, that where the product of combustion was solid, Lavoisier did not estimate the caloric retained by it, supposing in all cases the amount to be small, or perhaps that there was no caloric combined with it.

With regard to the light, which appears in cases of combustion, it did not appear to attract the attention of Lavoisier,

* Elements of Chemistry, vol. i. chap. v. Am. ed.

and little or nothing is said of its source. From some parts of his work, it may be inferred, that he was inclined to the opinion of the identity of light and caloric, or that they are modifications of the same matter, and, consequently, that both might be derived from the same substance. He might also have considered the light as emanating from the oxygen gas for the purpose of overturning the hypothesis, which was proposed by Macquer, and embraced by many other chemists, that light was the phlogiston of Stahl, and existed in combination with all combustibile bodies.

From what has been said, it will appear that Lavoisier's theory of combustion inferred a decomposition, and a combination, the combustibile body at a certain temperature decomposing the oxygen gas, by which its caloric and light were rendered sensible, while it united with its base, and formed the product of combustion.

CCCCCLXXXII. At the time that Lavoisier was engaged in the researches above mentioned, the subject of heat as connected with combustion and respiration, was investigated in a philosophical manner by Dr. Crawford, and the results of his investigations all tended to confirm the general conclusions of the French chemist. The view which he took, however, of the mode in which caloric existed in bodies was different from that of Lavoisier; for instead of considering it as chemically combined with the elastic fluids, he adopted the opinions of Dr. Irvine, that it resided in bodies in quantities proportional to their capacities. He demonstrated, that the caloric which was apparent during combustion must proceed from the diminution in the capacity of the oxygen gas, and that none of it could be derived from the combustibile body; for it appeared from his experiments, that the capacities of the latter were increased by combination with oxygen. Thus the calx or oxide of iron was found to have a capacity for caloric twice as great as iron in its metallic state, yet the difference in the capacity of oxygen gas, and the oxygen, when combined with the metal, was such as to produce a quantity of calo-

ric, during the combustion of the iron, sufficient to have raised the temperature of the oxide 11670° .* The capacity of charcoal is stated to be 0.2631, and of oxygen 4.7490, that of water being considered as 1.0000; when these elements combine with the phenomena of active combustion, the product formed is carbonic acid, the capacity of which is 1.0454; this number is higher than that appropriated to its base, yet it has been calculated by Crawford, that the caloric produced by the conversion of atmospheric air into carbonic acid is such, if it were not dissipated, as would be sufficient to raise the air, so changed, to four times the excess of the heat of red hot iron above the common temperature of the air, or equal to 4650° .† Presuming, therefore, upon the correctness of the data upon which his investigations rested, and upon the accuracy of the experiments, by which they were illustrated, his conclusion must be adopted, “that the most important facts, relating to the inflammation of combustible bodies, may readily be explained upon the principle, that the heat which is excited in combustion is derived from the air.”

CCCCCLXXXIII. It has been remarked, that the light which also accompanies this process was supposed by Lavoisier, and indeed most of his immediate associates, to proceed from the oxygen gas, in which, like caloric, it existed in the state of chemical combination. That this is its source, however, has been, by later researches and observations, rendered extremely doubtful; it is rather believed to be furnished by the combustible body, and several facts connected with this subject, appear to warrant this conclusion. When a combustible is combined with oxygen, the presumption is, that the light, which pre-existed in one or both, has been disengaged, yet, it not unfrequently happens, that when this product is heated with another inflammable body, the oxygen is transferred to it, and much light is emitted. The combustion of gun-powder is a familiar example of this kind, and there is a

* Experiments and Observations on Animal Heat, &c. p. 417. 2d ed.

† Ibid, p. 356.

copious emission of luminous rays, when charcoal is projected upon melted nitre, or chlorate of potash. But the argument may be more strongly sustained by the circumstances which accompany the combinations of combustible bodies with each other. It has long been known, that when copper, or iron in a divided state, is mixed with powdered sulphur, and exposed to heat in a close vessel, they unite, and that at the same moment the mass becomes red hot. The two metals, potassium and tellurium, when heated together, enter into combination, and evolve both heat and light.

It may be remarked, also, that the colour of the light is apparently dependent altogether upon the combustible body, and that the quantity evolved is not proportional to the amount of oxygen with which it combines, for hydrogen, which unites with a large quantity of this element, furnishes less light than charcoal, where the proportion of oxygen is smaller; and the combustion of phosphorus is more brilliant than either, though phosphoric acid contains less oxygen than fixed air, or water. Hence, although it has not been proved that none of the light in combustion proceeds from the oxygen gas, yet facts are in favour of the opinion, that it is contained in the inflammable bases. If this conclusion be adopted, combustion must be regarded as an example of *Double Affinity*. Oxygen gas is composed of a base combined with caloric, and the combustible body likewise of a base, united with light; when these compounds are brought into contact at a certain temperature, both are decomposed, the two bases combine with each other, and form the product of combustion, or the burned body, while the caloric of the one unites with the light of the other, and the two constitute flame.

CCCCLXXXIV. But there are facts which at first view appear to be not only inexplicable, but even directly opposed to the principles of this theory. It has been shown by Dr. Crawford, that whenever the capacity of a body for heat is diminished, caloric is disengaged, and that they are proportional to each other; and Dr. Black demonstrated that sub-

stances in passing from the ærial to the liquid, or from the liquid to the solid form, produced a given rise of temperature. Hence, if the caloric, which is manifested in the combinations of oxygen, previously existed in that gas, there is no obvious source of the great heat which is often given out during the transfer of oxygen from a solid compound to a combustible base. That this is the case, is demonstrated by a multitude of facts. In all the examples of *deflagration*, which consists in the decomposition of salts containing oxygen by inflammable bodies, the temperature is greatly increased; the same effect is perceived when such compounds are exposed to percussion with phosphorus, or when oxid of mercury is heated in contact with some of the metals, the result being an actual combustion. But the most familiar fact of the kind is that of gun-powder. This composition is a mixture of charcoal, sulphur, and nitre; if it be exposed to a certain temperature, the oxygen of the salt is transferred so quickly to the combustible bodies, and large bulks of elastic fluids are formed with so much rapidity, that inflammation accompanied with explosion, and a vivid light, together with a high degree of heat, are suddenly produced. Here then is a quantity of caloric disengaged, notwithstanding the oxygen is in a solid state, in which it might be supposed to have already parted with the greatest proportion, and, what is more, notwithstanding that very nearly half the weight of the elements of the powder assume the elastic form, and consequently suffer an increase of capacity for caloric. Upon the assumption that the theory of combustion which has just been stated is correct, this phænomenon can be explained only in one way, and it is that first proposed by some of the French chemists, and afterwards more formally by Brugnatelli. It is supposed that when oxygen combines slowly with combustible bodies without the phænomena of active combustion, it still preserves the caloric which is essential to it in the form of gas; in this way it unites with all the metals, and may be termed *thermoxygen*; but in uniting with

those bases, the products of which are acids, its caloric is disengaged, and it may then be called *oxygen*. Thermoxygen is found in combination with bodies existing in different forms, and it is these only which produce light and caloric during their decomposition by inflammable bodies. This mode of explanation, however, is altogether hypothetical; if adopted it must be merely from the ease with which it enables us to explain these anomalous cases of combustion, and if rejected, the phænomena must be considered as inexplicable upon the principles of the present theory.

CCCCCLXXXV. It is undoubtedly true, that the conclusion of Lavoisier when applied to common cases of combustion, or to those processes which are the subjects of daily and familiar observation, is correct, that it may be considered as the act of union of an inflammable body with oxygen. It is equally correct that the light and heat which are evolved are proportional to the purity of the gas which supports the combustion; but the progress of chemistry has made us acquainted with a number of facts, in which all the phænomena of combustion are manifested, during the combination or decomposition of bodies, notwithstanding that oxygen is not present. If the fundamental proposition in this theory be granted, it will be necessary to exclude from our ideas of combustion all the facts alluded to above, and if, on the other hand, we define combustion to be a total change of properties accompanied with the copious emission of light and heat, the theory of the French chemist can no longer be received as unrestricted and universal in its application. The fact is, that Lavoisier drew his deductions from the most common and obvious of the phænomena of fire, and applied the principles which he established to the elucidation of all combustible processes. But that they are not capable of explaining all cases of this kind may be shown among others by the following example. When the metal, called potassium, is gently heated in sulphuretted hydrogen gas, it takes fire and burns with great brilliancy, hydrogen gas is liberated, and a sul-

phuret of potassium formed, which, when treated with muriatic acid, gives off a quantity of sulphuretted hydrogen equal in volume to the gas previous to the experiment. It has been demonstrated by M. M. Gay-Lussac and Thenard, that these results are sufficient to prove that oxygen existed neither in the sulphur, nor in the sulphuretted hydrogen, for if this substance were present, the same bulk of the gas could not have been produced; yet the combination of the elements potassium and sulphur is not only accompanied with light and heat, but is so rapid as to cause the phænomenon of *flame*, for say these chemists, à peine le métal étoit-il fondu, qu'il s'enflamme vivement;* and were a person ignorant of the theories upon this subject to view this action, he would, without doubt, consider it as a case of burning or of combustion. But according to the principles of Lavoisier, the inflammation of the potassium cannot, in this instance, be viewed as such, because it is not a combination with oxygen; yet, what would be equally calculated to excite the wonder of the unlearned, the name of combustion must be given to the action which produces the rusting of iron under water, or the formation of carbonic acid in the pulmonary system of living animals. That the theory of Lavoisier leads to these conclusions is obvious from what has been stated, and it is confirmed by the fact that the latest of the French systematic writers upon chemistry, M. Thenard, has described the oxides under the name of *Corps brûlés*, or burned bodies. Yet the actions which cause the evolution of nitrous oxide from nitrate of ammonia, or of nitric oxide from mercury, and diluted nitric acid, are not accompanied with the emission of light and heat. If the definitions of Dr. Thomson and Dr. Murray be adopted, and they both explain the phænomena of combustion in conformity with the doctrines of Lavoisier, at least so far as to consider it as a process in which oxygen combines with the burning body, there are many other examples of this kind of action which are not owing to the pre-

* Recherches Physico-Chimiques, t. i. p. 194—202.

sence of that element. Thus, there is a change of properties, accompanied with the copious production of calorific and luminous rays, when potassium is heated in exhausted vessels with sulphur, phosphorus, tellurium, and arsenic; and when brought into contact at a moderate increase of temperature with cyanogen, it is heated, according to Gay-Lussac, to incandescence. The same phænomena may be remarked in the formation of many of the sulphurets and phosphurets, and in fact a gradation in the intensity of the actions which produce the appearances of combustion may be traced from the inflammation of phosphorus in oxygen gas, to the feeble light emitted during the combination of the same substance with potassium.

In order to reconcile these cases with the commonly received theory of combustion, Dr. Thomson has applied to their union the name of *semi-combustion*; thus with regard to the sulphurets and phosphurets, the sulphur and phosphorus are supposed to act the parts of supporters of combustion, "for they are melted and therefore contain a great deal of caloric; the metal or earth acts the part of a combustible; for both contain light as a component part. At the instant of combination the sulphur or phosphorus combines with the metal or earth; while the caloric of the one, and the light of the other, fly off in the form of fire."* Upon the same principle he explains the curious facts discovered by Berzelius, that many of the oxides, such as the green oxide of chromium, and those of tantalum and tellurium, when heated to redness take fire, and burn for an instant without increasing in weight, for the oxygen and the metal in these instances, entering into more intimate combination, evolve a portion of their caloric and light. The propriety and expediency, however, of employing the term semi-combustion is very questionable. It would be difficult, if not impossible, to define its limits, and, even if they were, the specific heat of sulphur or phosphorus, for example, would not be sufficient to account

* System of Chemistry, vol. i. p. 146. 5th ed.

for the quantity of caloric disengaged in its combination. It may also be objected that it is in fact substituting another body for oxygen, and virtually admitting that the presence of that element is not essential to combustion; and with regard to the oxides, the same difficulty occurs as in the case of the decomposition of nitrate, or chlorate of potash by combustible bases, the necessity of supposing that, although oxygen by its union with a base have been reduced to the solid form, it still retains a large portion of its caloric.

We have hitherto said nothing of the phenomena which are presented during the combinations of chlorine and iodine, because the facts already stated appeared sufficient to show that the fundamental proposition of the theory of Lavoisier could not be applied to all cases of combustion. We have been withheld also from mentioning these circumstances, because, by many, the real nature of these bodies is still thought to be involved in obscurity, or, at least, it must be conceded that neither of the theories upon this subject can be considered as universally established. If, however, the simple nature of iodine and chlorine be adopted, and the reasons why this opinion may be thought correct have been already detailed, a great number of unequivocal cases of combustion must be admitted, where the agency of oxygen cannot be traced; and the conclusion may perhaps be drawn, that combustion is a general and indefinite term, which may be applied rather to cases of the combinations of bodies which exercise intense mutual affinities, than to the presence of one specific substance; but even if this deduction be not admitted, the impossibility of forming a consistent and satisfactory theory of combustion, upon received principles, will appear on investigating more particularly the source of the caloric which is produced in these processes.

CCCCXXLVI. The difficulties experienced in determining the quantities of caloric, and the mode in which it exists in bodies, are such, that after the experiments of Black, Irvine, and Crawford, among the English, and M. M. Lavoisier,

sier and La Place, among the French chemists, little was done upon this subject, if we except the researches of Mr. Dalton and Count Rumford, until the subject was examined in 1812, with great precision by M. M. Berard and De la Roche.

It has been stated, that Dr. Black conceived caloric to be chemically combined with ponderable matter, and that Dr. Irvine supposed it to exist in them in consequence of an inherent power which he termed their *capacity* for containing heat. The ideas of Irvine upon this subject were embraced by Dr. Crawford, and, after many interesting and delicate experiments, he applied the doctrine of capacity to explain the production of heat, in the processes of combustion and respiration. His experiments and calculations were founded upon a theorem which was furnished by Dr. Irvine, who endeavoured to establish the two propositions, that the capacities of bodies remain the same, so long as they retain the same forms, and that the absolute or entire quantity of caloric which they contain may be ascertained by the amount of this principle given out during a change of state; or in other words by the difference in capacity in a body before and after a change of form. For example, the capacity of ice, according to Irvine, is to that of water as 8 to 10; now when the liquid freezes, it gives out 140° , and its capacity is diminished $\frac{1}{3}$; hence, presuming the capacities to be uniform, the absolute caloric in ice will be $140^{\circ} \times 4 = 560^{\circ}$, and in water, $140^{\circ} \times 4 = 560^{\circ} + 140^{\circ} = 700^{\circ}$. Water, then, upon this hypothesis, contains 700° of heat, so that when reduced to the state of total privation, the thermometer would sink to -700° . This point has been called the *absolute*, or *real zero*. It is obvious, that the degree, at which we suppose bodies to be entirely deprived of their caloric, must in this view be dependent upon the difference in capacity of the same body in two states, and that any error in the estimation of the relative capacities, must have a corresponding influence upon the calculated amount of the absolute heat. Accordingly, when it was found that the capacity of ice was to that of water as 9 to 10, the

real zero required to be placed at -1400° ; for $140^{\circ} \times 9 = 1260^{\circ}$, and $140^{\circ} \times 9 + 140^{\circ} = 1400^{\circ}$. Dr. Crawford arrived at his conclusions upon the same principle, viz. of ascertaining the absolute heat of bodies, and afterwards the difference between the amount of absolute caloric in the same body in different states, and from the heat communicated to a given weight of water by the combustion of known weights of hydrogen and oxygen, he was induced to fix the absolute zero at -1551° .*

But, that little dependance can be placed upon the experiments which have been made for the purpose of determining the temperature at which bodies would cease to contain caloric, may be shown by the results exhibited in the following table, the mean of the calculations, only, of the different chemists being expressed.

Irvine	-	-	-	-	-	-	-	-	700°
Black	-	-	-	-	-	-	-	-	1400°
Crawford	-	-	-	-	-	-	-	-	1551°
Gadolin	-	-	-	-	-	-	-	-	1400°
Lavoisier and La Place	-	-	-	-	-	-	-	-	4460°
Dalton	-	-	-	-	-	-	-	-	6150°

The real zero having been found by Dr. Crawford to be -1551° , it was inferred, that by ascertaining the quantity of caloric communicated by the airs in cooling a certain number of degrees, to a definite portion of water, and determining the ratio of their specific gravities, or quantities of matter, he should be enabled to calculate their relative capacities for caloric. This was done, and the capacity of water being taken as unity, or 1.0000, the capacities of the airs he examined were of

* Essay on Animal Heat, p. 265. 2d ed.

Azote	-	-	-	-	-	-	0.7936
Carbonic acid	-	-	-	-	-	-	1.0454
Atmospheric air	-	-	-	-	-	-	1.7900
Oxygen	-	-	-	-	-	-	4.7490
Hydrogen	-	-	-	-	-	-	21.4000

Having established the facts, that the absolute zero was -1551° , that the capacities of elastic fluids were uniform, or nearly so, at all temperatures while under the same form, that the caloric evolved during their combinations was the consequence of a change of capacity in the airs themselves, and that the amount of the heat produced was proportional to the difference in capacity, before and after union, he proceeded to apply the principles, thus deduced, to the phænomena of combustion and respiration. The mode by which he accounted for the heat disengaged in these processes may be illustrated by the following examples. It is known, that while charcoal is consuming, much caloric is rendered sensible, but it appears, that previous to the combustion, the capacity of charcoal is equal to 0.2561, and that of oxygen gas to 4.7490; after the process is concluded, the charcoal and oxygen are found combined with each other in the form of carbonic acid, the capacity of which is 1.0454; hence, the capacity of the charcoal must have been increased 0.9093, and the capacity of the oxygen gas diminished 3.7036; supposing the difference, before and after combustion, to amount to 3, and the absolute heat to be 1551° , and further, that the whole heat is derived from the oxygen gas, the quantity of caloric disengaged during the burning of the charcoal will be 1551×3 , or 4653° ; and the temperature at which bodies become luminous being considered as 1050° , it will be seen, that this inflammation produces a quantity of caloric sufficient to heat the product of the combustion three times higher than red hot iron above the common temperature of the air.

The comparative heat of pure oxygen is to that of water, as 4.75 to 1, nearly; and the comparative heat of pure hy-

drogen is to that of water as 21.4 to 1. The specific gravity of a mixture of 1 volume of oxygen, and 2 volumes of hydrogen, is to the specific gravity of water as 1 to 2119, and the heat produced by the combustion of 11 parts of the mixture raised the temperature of 20.517 parts of water 2.4 degrees. The capacity for heat of the mixture is to that of the water as 7.11 to 1;* whence it follows, that during the active combination of 1 volume of oxygen gas with 2 volumes of hydrogen gas, a quantity of caloric is produced, equal to 1551×6.11 , or 9476° .

CCCCLXXXVII. It having been found by Lavoisier, that the quantity of caloric given out by different bodies, during their combustion, was insufficient to melt so much ice, as was estimated by calculation, he drew the conclusion, that the excess of this heat entered into chemical combination with the product of the action. Thus, 1 pound of charcoal during its combustion absorbs or combines with 2.5714 pounds of oxygen, and melts 96.5 pounds of ice, but according to calculation, the quantity of caloric, which ought to be disengaged, would be sufficient to liquefy 171.414 pounds of ice, and he therefore concluded, that the carbonic acid contained enough caloric to form 74.914 pounds of water. A pound of hydrogen combined with 5.66 pounds of oxygen, and formed 6.66 pounds of water, and the heat given off was found by experiment to melt 295.12 pounds of ice, but it ought to have formed 377.7 pounds of water, hence, there must have existed in the water as much caloric as would have melted 82.6211 pounds of ice. From this it appears, says he, that water, even in the state of ice, contains a considerable quantity of caloric, and that oxygen, in entering into combination, retains likewise a good proportion.†

CCCCLXXXVIII. Notwithstanding that Dr. Black, M. Lavoisier, and other chemists, maintained the hypothesis of combined caloric, the doctrines of Irvine and Crawford upon the subject of capacity appeared to prevail, and after the

* Crawford on Animal Heat, p. 261.

† Elements of Chemistry, vol. i. p. 120. Am. ed.

work of the latter on *Animal Heat* was published, a work which exhibits the results of numerous delicate experiments, and much profound calculation, the production and absorption of caloric in chemical action were attributed to changes in the capacities of bodies, and the high temperature accompanying processes of combustion was supposed to proceed from the oxygen gas, and to be developed by the reduction in its capacity while combining with the inflammable body. But the results of experiments made by M. M. Berard and De la Roche, and published in 1813, must have the effect, if confidence can be placed in them, to alter the opinions of chemists upon this subject. They have shown, that changes in the capacities of bodies are very far from being sufficient to account for the caloric evolved in these processes, that the difference in these capacities before and after union is in most cases much less than has been estimated by Crawford, and that in some, the product of combustion actually possesses a greater capacity, than the amount of those of its elements previous to their combination. These experiments are the most recent which have been executed, their authors had the advantage of choosing their methods from among those employed by preceding chemists, their apparatus, though complicated, was delicate, and adapted to the purpose, and the memoir in which they were detailed gained the prize proposed by the National Institute of France, for the best dissertation upon the subject. These facts are sufficient to entitle them to confidence, independently of the high character sustained by these philosophers.

CCCCLXXXIX. The conclusions of M. M. Berard and De la Roche were derived from experiments made with a calorimeter of a new construction, consisting essentially of a small cistern containing a spiral tube, through which an uniform current of air heated to a certain temperature was made to pass, and to give out its heat to a known weight of water by which the worm was surrounded. The specific heat of the gases was ascertained by two methods, the first

formed upon the principle, that this heat was proportional to the maximum of the elevation of temperature in the calorimeter by a current of hot gas. To compare these specific heats with those of water, it was only necessary to compare the effect produced upon the calorimeter by one of the gases, and by a current of hot water moving so slowly that its effects should not be much more considerable than those of the gas itself. The second method of discovering the ratio between the specific heats of water and the gases consisted in determining by calculation the quantity of heat given out in a certain time by the calorimeter, when the current of hot air had rendered it stationary.* We shall give in the appendix the table stating at large the results of these experiments, but a few will be here introduced, that the specific heats may be more conveniently compared with the capacities of the same bodies, as stated in (CCCCCLXXXVI.) from the work of Crawford. It must be remembered that the numbers denote the specific heats of *equal weights* of the substances.

Water	-	-	-	1.0000
Azote	-	-	-	0.2754
Carbonic acid	-	-	-	0.2210
Atmospheric air	-	-	-	0.2669
Oxygen	-	-	-	0.2369
Hydrogen	-	-	-	3.2936

Now if change of capacity in oxygen gas be the only mode by which the production of caloric in combustible processes is to be explained, it is obvious that the rise of temperature in such cases is absolutely inexplicable. It is well known that the combustion of hydrogen, when mixed with a certain proportion of pure oxygen, produces a stronger heat than can be effected by art in any other way; hence, the diminution of capacity ought to be proportionally great, and the differ-

* *Annals of Philosophy*, vol. ii. p. 134.

ence between the capacities of oxygen and hydrogen gases, and water, more evident than between any other substances before and after combustion. But this is so far from being the case, that water, according to M. M. Berard and De la Roche, absolutely possesses a greater capacity than an equal weight of its elements. We may state the composition of water in round numbers to be 12 parts of hydrogen, and 88 of oxygen by weight. The capacity of $\frac{12}{100}$ of hydrogen is 0.3952, and of $\frac{88}{100}$ of oxygen 0.2077, the sum of their capacities is 0.6029, but the capacity of water is 1.0000, whence it follows, that if diminution of capacity were the only source of the caloric in combustion, instead of obtaining by the inflammation of hydrogen a degree of heat sufficient to melt quartz, and volatilize platina, the effect must be *cold*, or an absorption of caloric.

In the production of carbonic acid there will be, upon these calculations, an extrication of caloric, but the quantity evolved by this diminution of capacity, must bear but a very small proportion to that which is actually disengaged. Having no data from the experiments of Berard and De la Roche to calculate from the capacities of oxygen and charcoal, the degree of heat evolved may be shown by the difference in the capacities of oxygen and carbonic acid, which, as will be seen in the preceding table, amounts only to 0.0151 or $\frac{15}{10000}$. Now the elements are combined in carbonic acid in round numbers in the proportion by weight of 72 of oxygen, and 28 of carbon, and as 1 pound of charcoal, during its combustion, combines with 2.57 pounds of oxygen, and melts, according to Lavoisier, 96.5 pounds of ice, each pound of oxygen must give out 5256° ; hence, if we adopt the theorem of Dr. Irvine, the absolute heat of oxygen gas must amount to the enormous sum of $5256^{\circ} \times 16$, or 84096° . Should we take Dr. Crawford's number, 0.2631, as the capacity of charcoal, the capacity of carbonic acid would be greater than that of oxygen, for $\frac{28}{100}$ of 0.2631 are .0734, and $\frac{72}{100}$ of 0.2361 are 0.1815, and $.0734 + 0.1815 = 0.2569$, but the capacity of oxy-

gen gas being 0.2361, that of carbonic acid the product of its combination with carbon, is superior, and no heat should be disengaged.

In the formation of minium or red oxide of lead, the oxygen passes from the gaseous to the solid form, and we have a right to conclude that a quantity of caloric proportional to the condensation is disengaged, yet it has been found that the capacity of the oxide is greater than the mean of the capacities of oxygen and metallic lead.

In calculating, therefore, from the experiments of M. M. Berard and De la Roche, it necessarily follows, that the evolution of caloric, during combustion, cannot be ascribed to the change in the capacities of the bodies employed, or at least that this change is not the only source of the heat; we must therefore look to some other cause, and this, it is suggested by the French chemists, may perhaps be found in the disengagement of the combined caloric existing in oxygen, and the combustible bodies. It is necessary, therefore, unless we deceive ourselves, they observe, to abandon the hypothesis which ascribes the evolution of heat in cases of combination to a diminution of the specific heat in the bodies combined, and admit, with Black, Lavoisier, La Place, and many other philosophers, the existence of caloric in a state of combination in bodies. The knowledge of the specific heat of oxygen alone would be sufficient to induce us to adopt this opinion; for it is so small that it is almost impossible for us to account for the great quantity of heat disengaged during the combustion of the greatest number of bodies, unless we suppose that this heat previously existed in a state of combination. Accordingly, when the opposite hypothesis was adopted, philosophers were obliged to suppose the specific heat of this gas fifteen times greater than it is in reality. But, they continue, we must not suppose that there exists no relation between the specific heat of compounds, and that of their constituents. Too many facts prove this relation to make it possible to deny it. Water, in this respect, constitutes the

greatest deviation which has been observed, yet it does not exceed $\frac{1}{3}$ of the specific heat of this fluid. In general, we may say, that the constituents of a body communicate to it their specific heat. This is very observable in the combinations of hydrogen, which has the highest specific heat of all known bodies. The compounds which it forms have a much greater specific heat than other bodies; hence the great specific heat of water, of olefiant gas, and of animal and vegetable substances.

It has been observed that in the modern theory of combustion, the caloric of the supporter, and the light of the inflammable body are supposed to unite with each other, and form a compound which flies off, to use the language of Dr. Thomson, in the form of fire. Until very lately, chemists appeared to have been satisfied with this explanation, and the many curious phænomena of *flame* were overlooked. But that this supposed combination of the two ethereal substances is not sufficient to account for these appearances will be evident, from an attentive examination of the important and interesting researches and experiments of Sir H. Davy, of which, as well as of those of other chemists, we shall now give a concise account.



Flame.

CCCCXC. It has been remarked, that Hooke supposed flame to be volatile combustible matter heated red hot, and that Newton sanctioned the idea, that it consisted of vapour, the temperature of which was raised to ignition. When the modified doctrine of Stahl was in vogue, and hydrogen was considered as the principle of inflammation, the phænomenon of flame was inferred to arise from the disengagement of this element. In 1811, Dr. Coxe, Professor of Chemistry at Philadelphia, maintained the phlogistic doctrine, in his *Observations on Combustion and Acidification*. He inferred, that in all cases,

a base was required to sustain flame, and that hydrogen constituted this base. "That caloric and light," says he, "do not alone constitute flame, is, I think, evident; since, united as they are supposed to be, in the solar rays, they do not reach us in that form. The reason is obvious; they cannot produce flame unless united with the inflammable principle, which they always meet with, as hydrogen, in every combustible body. The most powerfully concentrated solar rays produce no flame in incombustibles.—They fuse and volatilize the hardest incombustible, 'tis true, but no flame follows: yet caloric and light are both present in the concentrated rays, as well as, probably, in the body exposed to them; but the defect of this inflammable principle, as a constituent of the body, effectually precludes the possibility of flame."

CCCCXCI. While noticing the properties of coal-gas, we had occasion to state the experiments of Sir H. Davy, by which he was led to the discovery of a method of obviating the danger of explosion in coal-mines, from the presence of fire-damp mixed with atmospheric air. In the detail of those experiments, he drew some conclusions respecting the nature of flame which were both novel and interesting. The subject has since been prosecuted by him with his accustomed ingenuity and success. The intensity of the light of flames he has found to depend principally upon the production and ignition of solid matter in combustion, and that the heat and light in this process are in a great measure to be considered as independent phenomena. Different gases require different degrees of heat to continue their combustion, and when their temperatures are reduced below a certain point, they cease to burn. The effect of rarefaction upon flame seems to depend upon the fact, that a sufficient degree of heat is not communicated to the elements to enable them to combine. When the flame of hydrogen gas about $\frac{1}{6}$ of an inch in length, and issuing from the fine orifice of a glass tube was introduced into a receiver, upon the table of an air-pump, the flame enlarged as the air was exhausted, and when the pressure was 4 or 5 times less than that of

the air, it had reached its maximum size, it then gradually diminished below, but burned above till the pressure was 7 or 8 times less, when it became extinguished. When a larger jet was employed, it not only burned longer, but in a more rarefied atmosphere, the pressure amounting only to $\frac{1}{10}$ of the original weight. The point of the glass tube also became white hot, and continued red hot until the flame was extinguished. It was obvious, that the flame of the first jet was not extinguished from the deficiency of oxygen, but that the heat communicated to the gas by the tube might have been the cause, that the combustion continued longer in the last experiment. In order to ascertain this point, a piece of platinum wire was coiled round the top of the tube, so as to reach into and above the flame, the jet of gas $\frac{1}{6}$ of an inch in height was again lighted, and the exhaustion made; the wire soon became white hot in the centre of the flame, and a small point of the wire near the top was fused; it continued in this state till the pressure was 6 times less; when it was 10 times, it continued red hot at the upper part, and so long as it was dull red, the gas, though extinguished below, continued to burn in contact with the hot wire, and the combustion terminated only when the pressure was reduced 13 times. The combustibility of hydrogen, therefore, is not affected, either by an increase or diminution of pressure, and it will burn so long as the heat which it produces is sufficient to keep up the combustion, which appears to be when it is capable of communicating visible ignition to metal.

Hence it should follow, with respect to other combustible bodies, that those which require the least heat for this process ought to burn in more rarefied air, than those which require more heat; and that those that produce much heat in their combustion ought to burn, other circumstances being the same, in more rarefied air than those which produce little heat; and these conclusions were confirmed by experiment. Thus, the flame of olefiant gas which neither requires, nor produces in its combustion, much more heat than hydrogen.

ceased to burn when the pressure was diminished 10 or 11 times, while that of carburetted hydrogen, which gives out less heat, and requires much more for its combustion, was extinguished when the pressure was below $\frac{1}{3}$. Air, rarefied 6 times, extinguished the flame of carbonic oxide, of sulphuretted hydrogen when the pressure was $\frac{1}{7}$; and of sulphur, when it amounted to $\frac{1}{20}$. But phosphuretted hydrogen produced a flash of light in the best vacuum that could be made. Oxygen and hydrogen will not explode by electricity when rarefied 18 times, but the explosion of chlorine and hydrogen may be produced by the same means when rarefied 24 times. But if the first mixture, when thus rarefied, be heated strongly, explosion will take place by the passage through it of the electric spark. Hence it appears, that by preserving heat in rarefied air, or giving heat to a mixture, inflammation may be continued, when under common circumstances it would be extinguished.

It has likewise been shown by Sir H. Davy, that expansion by heat, instead of diminishing the combustibility of gases, as was the opinion of M. de Grotthus, enables them, on the contrary, to explode apparently at a lower temperature; because the mixture is already supplied with the heat which in the other case must be expended in raising the temperature of such a mixture. Oxygen and hydrogen gases in a dry state, and in mixture, were exploded in a tube, even before it became red hot, and by exposing the gases to a degree of heat between the boiling point of mercury, and visible ignition, they were made to combine without explosion, and steam was produced, the volume of which was exactly equal to that of the original gases. This effect of slow combination was found to be unconnected with their rarefaction by heat. Charcoal, and the elements of olefiant gas, were proved in the same way to combine without combustion with oxygen at a temperature little above the boiling point of mercury. Other experiments likewise confirm the principle above stated. Sir Humphry Davy has also proved, that the opinion of M. Berthollet, Dr.

Higgins, and other philosophers, that the compression in one part of an explosive mixture, produced by the sudden expansion of another part by heat or the electric spark, is the cause of combination, is not correct, and that the real cause of the combustion is the *heat* given out by the compression of the gases ; and that at certain elevations of temperature, whether in rarefied or compressed atmospheres, explosion or combustion occurs, i. e. bodies combine with the production of heat and light.

Some very curious facts respecting the influence of elastic fluids, in preventing explosion in inflammable mixtures, were discovered by Sir H. Davy. Thus 1 part of an explosive mixture of oxygen and hydrogen was prevented from burning by previous mixture with 8 parts of hydrogen, 9 of oxygen, 11 of nitrous oxide, 1 of carburetted hydrogen, 2 of sulphuretted hydrogen, $\frac{1}{2}$ of olefiant gas, 2 of muriatic acid gas, or $\frac{5}{6}$ of silicated fluoric acid gas. When the proportion of the gas was rather less, explosion was produced. In such cases the elastic fluids operate by their cooling powers to preserve the temperature below the exploding point, and this property depends upon two causes, the simple abstracting power by which they become quickly heated, and their capacity for heat which is great in proportion as their temperatures are less raised by this abstraction.

Whatever be the cause of the different cooling powers of the elastic fluids in preventing inflammation, they operate uniformly with respect to different species of combustion, and those explosive mixtures which require least heat for their combustion, require larger quantities of the different gases to prevent the effect, and *vice versa* ; thus, 1 of chlorine and 1 of hydrogen inflame when mixed with 18 times their bulk of oxygen, but a mixture of 1 of carburetted hydrogen and 2 of oxygen, is prevented from exploding by less than 3 times its volume of oxygen.

These conclusions, with respect to the cooling agency of an elastic fluid in preventing combustion, may be demonstrated

by the following beautiful experiment performed by this great chemist. Into a long bottle, with a narrow neck, introduce a lighted taper, and let it burn till it is extinguished; carefully stop the bottle and introduce another lighted taper, it will be extinguished before it reaches the bottom of the neck; then introduce a small tube containing zinc and diluted sulphuric acid, and at the aperture of which the hydrogen is inflamed; the hydrogen will be found to burn in whatever part of the bottle the tube is placed; after the hydrogen is extinguished, introduce lighted sulphur; this will burn for some time, and after its extinction, phosphorus will be as luminous as in the air, and, if heated in the bottle, will produce a pale yellow flame of considerable density.

Some experiments were made with the view of determining the effect of condensation in common air, upon flame, and the conclusion was drawn, that as rarefaction does not considerably diminish the heat of flame in atmospheric air, so neither does condensation considerably increase it; a circumstance of great importance in the constitution of our atmosphere, which at all heights or depths, at which man can exist, still preserves the same relations to combustion. Large quantities of steam were found necessary to prevent explosion; a mixture of common air and carburetted hydrogen, the least inflammable of the explosive mixtures, required $\frac{1}{3}$ of steam to prevent this effect, whereas explosion was prevented by $\frac{1}{5}$ of azote.

In all cases the quantity of heat communicated by combustion, will be in proportion to the quantity of burning matter coming in contact with the body to be heated. Thus the blowpipe and currents of air operate; with pure oxygen compression produces an immense effect, and with currents of oxygen and hydrogen there is every reason to believe, that solid matters are made to attain the temperature of the flame. The temperatures of flames are probably very different. By detonating cyanogen with oxygen, the temperature was found, by Sir H. Davy, in calculating upon the data

furnished by M. Gay-Lussac, of the expansibilities of air, to be above 5000° . The heat of gaseous carbon in combustion in this gas appears more intense than that of hydrogen, for a filament of platina melted in the former in atmospheric air, but was not fused in a similar flame of the latter.

Flame is gaseous matter heated so highly as to be luminous, and that to a degree of temperature, beyond the white heat of solid bodies, as is shown by the circumstance that air not luminous will communicate this degree of heat. If a fine wire of platina be held about $\frac{1}{20}$ of an inch from the exterior of the middle of the flame of a spirit lamp, and the flame be concealed by an opaque body, the wire will become white hot in a space where there is no visible light.

CCCCXCII. The author then proceeds to state the theory of the operation of the safety-lamp in preventing explosions in mines, to which we have already alluded, (CCCCIV.) and it is illustrated among others by a very simple but beautiful experiment. Let the smallest possible flame be made by a single thread of cotton, immersed in oil and burning upon the surface of oil;* it will be found to be about $\frac{1}{30}$ of an inch in diameter. Let a fine iron wire of $\frac{1}{180}$ be made into a circle of $\frac{1}{10}$ of an inch in diameter, and brought over the flame. Though at such a distance, it will instantly extinguish the flame, if it be cold; but if it be held above the flame, so as to be slightly heated, the flame may be passed through it without being extinguished. That the effect depends upon the power of the metal to abstract the heat of the flame, is shown by bringing a glass capillary ring of the same diameter and size over the flame; this being a much worse conductor of heat, will not extinguish it even when cold.

The facts above stated, says Sir H. Davy, explain why so much more heat is obtained from fuel when it is burnt quickly; and they show that in all cases the temperature of the acting bodies should be kept as high as possible, not only be-

* I have found tin-foil a convenient substance to support this attenuated wick.

cause the general increment is greater, but likewise because those combinations are prevented, which at lower temperatures take place without any considerable production of heat; thus, in the Argand lamp, and in the best fire-places the increase of effect does not depend solely upon the rapid current of air, but likewise upon the heat preserved by the arrangements of the materials of the chimney, and communicated to the matters entering into inflammation. These facts also explain the methods by which temperature may be increased, and the limits to certain methods; and the nature of the light of flames, and their form. When in flames pure gaseous matter is burnt, the light is extremely feeble; the density of a common flame is proportional to the quantity of solid charcoal first deposited and afterwards burned. The form of the flame is conical, because the greatest heat is in the centre of the explosive mixture. In looking steadfastly at flame, the part where the combustible matter is volatilized is seen, and it appears dark, contrasted with the part in which it begins to burn, that is, where it is so mixed with air as to become explosive. The heat diminishes towards the top of the flame, because at this part the quantity of oxygen is least. When the wick increases to a considerable size from collecting charcoal, it cools the flame by radiation, and prevents a proper quantity of air from mixing with its central part; in consequence the charcoal thrown off from the top of the flame is only red hot, and the greater part of it escapes unconsumed.

The facts above stated show that the luminous appearances of shooting stars cannot be owing to any inflammation of *elastic* fluids, but must depend upon the ignition of solid bodies. The velocity of motion of these bodies must be immensely great, and the heat produced by the compression of the most rarefied air from the velocity of motion must probably be sufficient to ignite the mass; and all the phænomena may be explained, if *falling stars* be supposed to be small solid bodies, moving round the earth in very eccentric orbits,

which become ignited only when they pass with immense velocity through the upper regions of the atmosphere, and if the meteoric bodies which throw down stones with explosions be supposed to be similar bodies which contain either combustible or elastic matter.*

CCCCXCIII. Sir H. Davy having ascertained that the temperature of flame was infinitely higher than that necessary for the ignition of solid bodies, considered it as probable that in certain combinations of gaseous bodies, although the increase of temperature were not sufficient to render the gaseous matters themselves luminous, yet, that it might have been adequate to ignite solid matters exposed to them. This conjecture he soon verified. It was found that when a fine platina wire was fixed above the flame of a safety-lamp, which was afterwards introduced into an inflammable mixture of coal gas, and allowed to remain until the flame was extinguished, that part of the wire which had been hottest remained ignited, and continued so for many minutes, and when removed to a dark room, it was evident that there was no flame in the cylinder. The same fact was proved by making a similar mixture, and introducing into it a heated platina wire, the metal immediately became ignited nearly to whiteness, continued glowing for a long while, and when extinguished, the inflammability of the mixture was found entirely destroyed. The same effects were obtained in mixtures of air with carbonic oxide, cyanogen, olefiant gas, and hydrogen gas, and in the last case with a rapid production of water. The same circumstance occurred with certain inflammable vapours, such as those of ether, alcohol, oil of turpentine, and naphtha. Let a drop of ether be thrown into a cold glass, or a drop of alcohol into a warm one. Let a few coils of wire of platina of $\frac{1}{80}$ or $\frac{1}{70}$ of an inch be heated at a hot poker, or a candle, and let it be brought into the glass; it will in some part of the glass become glowing, almost white hot, and continue in that state so long as a sufficient quantity of vapour and of air re-

* Philosophical Transactions for 1817. Part i. p. 45.

mains in the glass. If the experiment be made in the dark, a pale phosphorescent light is perceived about the wire, and it is connected with the formation of a peculiar acrid volatile substance possessing acid properties.* The only metals which have been found to answer this purpose are platina and palladium. By hanging some coils of fine platina wire, or a fine sheet of platina, or palladium above the wick of a safety-lamp, Sir H. Davy believes that a miner may be supplied with light in a mixture of fire-damp no longer explosive; and should his flame be extinguished by the quantity of fire-damp, the glow of the metal will continue to guide him, nor can there be any danger with respect to respiration, whenever the wire continues ignited, for even this phænomenon ceases when the foul air forms about $\frac{2}{3}$ of the atmosphere.

The facts above stated have given rise to a curious instrument, which is called the *Lamp without flame*. A fine platina wire is rolled in a spiral form, and supported upon the wick of a spirit-lamp; the alcohol is then lighted, and when the metal is ignited, it is extinguished; the heat of the wire causes a continued but slow combustion of the spirituous vapour, and this process produces so much heat, as to preserve the platina at the temperature of ignition. The heat is kept up by the imperfectly conducting and radiating powers of the metallic wire. For the success of this experiment, it is necessary that the wick should be straight, that there should be from 10 to 14 coils of the platina, and that half the number of coils should be upon, and the other half above the wick.

CCCCXCIV. The ideas of Sir H. Davy with regard to the constitution of flame, and his discoveries relating to the cooling effects of wire-gauze, have been verified and extended by Dr. Sym. He has shown, that the effect of a wire-gauze of the requisite fineness, when held over the flame of a candle is not that of depression, but of truncation. The lower part suffers no change in shape, size, or intensity; and the part which

* If the experiment be made with about half a drachm of ether in a wine-glass, the heat of the wire will be sufficient to inflame the liquid.

ought to be above has simply disappeared. If the gauze contain 36 meshes to the square inch, a few feeble streaks of red flame, with abundance of smoke will pass through it ; but if the meshes amount to 64, the flame will be permanently truncated. When a flame is thus divided, its structure may be viewed from above, and it then appears in the form of a narrow luminous ring, surrounding a disc which is not luminous ; and the direct perception is, that the lower segment of the apparent flame of a candle consists of only a thin superficial film of flame, which has the shape of a cup, surrounding the wick, and closing in upon it below, but filled with volatilized wax. When a flame has been truncated by a piece of wire-gauze, a stream of volatilized wax passes through it, and when the wire is sufficiently hot, it may be inflamed, and will continue to burn as if no gauze were interposed. But there is an interval between the two segments. The upper one presents the same appearance of a luminous ring, or film of flame, as the lower one ; and by applying a second metallic gauze to the superior flame, it may be bisected, and a portion of flame may be thus obtained between the two portions of net-work, which is neither connected with the wick below, nor terminated in an apex above. This intermediate segment has the structure of a short tube, through which, as through a conduit, the column of residuary vapour ascends. The results of these experiments are in exact conformity with the opinions of Sir H. Davy, of the nature of flame, and of the operation of wire gauze in preventing by its cooling powers the propagation of combustion in explosive mixtures. The conclusion drawn from them by Dr. Sym is, that wherever a stream of inflammable vapour or gas rises gradually into contact with the surrounding air, and combines with its oxygen so as to produce flame, that flame is and must be hollow. But he thinks that in those mixtures, such, for example, as charcoal with nitre, which contain within themselves the elements of combustion, and which for that effect require only the application of heat, the combustion is solid. Thus when

a phial containing hydrogen is turned up with its mouth open, the gas, as it ascends, may be inflamed, and the flame will be found hollow. If the mouth be inverted, and the hydrogen be inflamed, it will burn slowly, the flame gradually ascending into the vessel, and though not hollow, consisting merely of a thin film. But when oxygen and hydrogen are previously mixed, and the mixture is exploded, both the reason of the thing, and our own perception, as far as it goes, lead us to conclude, that the flame has not been superficial, but solid. Hence, as an ordinary flame is a permanent hollow combustion, we may define an explosion to be a momentary solid combustion; and this difference in structure will account for the difference of their intensity. If the permanency of a hollow flame could be combined with the intensity of a solid one, or in other words, if a lasting explosion could be produced, a powerful agent would be obtained for the chemist and the artist, and it was suggested by Dr. Sym. that this combination might be obtained by filling Newman's blow-pipe with a condensed mixture of oxygen and hydrogen, a fact which was verified about that time by Dr. Clarke.*

In concluding the subject of combustion, we must remark, that as many cases exist, in which the phænomena of this process are displayed, independently of the presence of oxygen, the conclusion is unavoidable, that this element can no longer be considered as essential; and as both caloric and light are often disengaged or produced, in circumstances which the doctrines of capacity cannot explain, that these appearances are the general results of great energy of combination or decomposition. The idea of combined caloric is obviously hypothetical, and it has never been proved that light constitutes a part of ponderable matter.

* Annals of Philosophy, vol. viii. p. 321.



CHAPTER IV.

OF THE ANALOGIES BETWEEN THE ELEMENTARY SUBSTANCES, AND THEIR COMPOUNDS HITHERTO DESCRIBED; AND OF SOME POINTS OF CHEMICAL THEORY.

CCCCXCV. All systematic arrangements of the subjects of chemistry must be more or less imperfect and arbitrary, because there is a chain of resemblance in the properties of all the elementary bodies, and it is impossible to describe the characters of one, without adverting to those of others, with which the student is presumed to be unacquainted. If we commence with the principles of the science, its laws can be demonstrated only by a reference to the mutual actions of bodies still unknown; and if individual substances be first described, the general terms which have been appropriated to classes of facts must be employed, and frequently but imperfectly explained. It may therefore be useful, as well as interesting, after having acquired some general knowledge of the most important chemical elements, and of the laws which govern them in their combinations, to take a cursory and collective view of their relations to each other, and of the analogies which are found to subsist between their compounds.

Although the supporters of combustion, and the acidifiable and inflammable bases have been, and must at present be considered as elementary, it by no means follows, that they are so in fact; on the contrary, some of them exhibit properties, which, in reasoning from analogy, would lead us to suspect that they were compounded; but as they have not yet been decomposed, the rule adopted in chemistry requires that they should still be regarded as simple.

CCCCXCVI. There is every reason to suppose, that oxygen is an element. The very extensive affinities it displays, and the energy with which it enters into combination, strong-

ly favour this belief, and it is strengthened by the fact, that the quantities of it which unite with other bodies are comparatively small.

The colour of chlorine, its solubility in water, and its high specific gravity and proportional number, seem to point out its compound nature. It may perhaps be ultimately proved to be composed of a base combined with oxygen, and its representative number is such, that it may be found to include 4 proportions of oxygen.*

Professor Berzelius, who is a strenuous defender of the doctrine of Berthollet, supposes muriatic acid to contain 2 volumes, chlorine 3, euehlorine 4, the bleaching liquid obtained from chlorine and potash 6, and chloric acid 8 of oxygen; and he asserts, that this view of the constitution of these compounds accords better with the doctrine of definite proportions than the new theory of chlorine. But that muriatic acid consists of a base united with oxygen, has been maintained by no other chemist, who adhered to the hypothesis of the illustrious French chemist; and the argument of Berzelius has lost its force since the discoveries of Sir Humphry Davy, and of Count Von Stadion.

The opinion which is adopted respecting the nature of chlorine may be applied with the same force to iodine. The general properties of this substance, its colour, whether in the solid or æriform state, its specific gravity, its inactivity, and the high proportional number by which it is represented, all favour the idea, that it is a compound. But on the other hand, its analogy to sulphur seems to point out a similarity in nature, it has never been decomposed, and must therefore be considered as simple.

Of all substances, hydrogen appears to have the greatest claim to the name of an element. The extreme levity, the small quantities by weight in which it enters into union, and the energy of the attractions, by which it is characterized, render the opinion very improbable, that it will ever be resolved into a simpler form of matter.

* Davy.—*Elements of Chem. Philos.* p. 277. Amer. ed.

The character of azote is more doubtful. The affinities which it exercises are comparatively feeble, and it is generally disengaged with ease from its combinations. Some facts have been stated in its history, which have led to the suspicion, that it is not simple, but no unequivocal experiment has yet been made to prove its compound nature.

With regard to the solid inflammable bases, and particularly carbon, phosphorus, and sulphur, the idea has been entertained, that they were compounds of bases and hydrogen; but this opinion has not been verified, and at present they must be regarded as strictly elementary.

CCCCXCVII. Oxygen, chlorine, and iodine exhibit distinct analogies. The two first support combustion in an eminent degree, and all three combine with simple bases to form binary compounds; and there is a general resemblance between the oxides, chlorides, and iodides. Chlorine and iodine also agree with each other in forming two sets of acids, one with oxygen, and the other with hydrogen. When the compounds of these elements with radicals are electrified in the voltaic circuit, oxygen, chlorine, or iodine is separated at the positive surface; but the compounds of chlorine and iodine differ from those of oxygen in the circumstance, that they are incapable of combining with acids. The acid compounds, in which chlorine and iodine are acidified by oxygen or hydrogen, are less energetic than those formed by the acidifiable solid bases with oxygen. Thus, sulphuric acid disengages fluo-silicic acid from siliceous fluor spar, but fluo-silicic acid decomposes the salts, of which chloric acid constitutes one of the ingredients.

Fluorine, or the basis of fluoric acid, so far as it is known, appears to be analogous to the three other supporters of combustion in forming binary compounds with bases, exhibiting neutro-saline properties, and in acquiring acid properties by its union with hydrogen.

CCCCXCVIII. But this class of bodies, though connected with each other by strict analogies, must not be considered as

insulated ; when viewed in relation to the simple inflammable bases, it will be found, that some of them possess many properties in common. Sulphur agrees with chlorine and iodine in forming an acid with hydrogen, and another with oxygen ; some of the iodates resemble the chlorates exactly, and most of them have a greater resemblance to the sulphates. The iodides, chlorides, and sulphurets in general exhibit the same phenomena with water ; and the action of sulphur, iodine, and chlorine upon the oxides, with or without water is precisely the same. M. Gay-Lussac affirms, that all the properties of iodine may be classed between those of sulphur and chlorine ; and as the two last coincide in many characters, he thinks that they ought to be formed into a class by themselves, which class may be distinguished by the property of being acidified by hydrogen.* In this way, however, chlorine and iodine would be removed from the places to which as important chemical elements, in a theoretical point of view, they seem to be entitled. Notwithstanding these points of resemblance, these elements and their compounds are found in other respects to differ materially from each other, and in all to bear a greater analogy to oxygen, and its compounds. Like oxygen in voltaic arrangements, they are determined to the positive surface, whereas sulphur is separated at the negative surface ; the compounds they form with metals strongly resemble those formed by oxygen ; they are electric, and many of them soluble in water, and possessed of acid properties ; whereas, those formed by sulphur are all non-electrics, and insoluble.†

Hydrogen is connected with the inflammable bases by the manner in which it combines with oxygen and chlorine. Azote exhibits no very distinct analogies ; like oxygen, however, it enters into the composition of some acids, and of ammonia, which is strongly alkaline, and it resembles carbon in the proportional quantity in which it enters into combination.

* *Memoir on Iodine.*

† Sir H. Davy.—*Journal of Science and the Arts*, vol. i. p. 283.

and in its want of attraction for metallic bodies. Like iodine and phosphorus, and sulphur, it unites in definite proportion with chlorine.

Boron has a considerable resemblance to carbon. They are both solid, infusible, and incapable of volatilization; they both require to be heated in order to combine with oxygen, and the results of their combustion are acids. They are insoluble in water, are not affected by acids, and according to Gay-Lussac and Thenard, boron agrees with carbon or charcoal in producing no alteration in chlorine.

Of the relations of silicon, we know little, as it has never been obtained in sufficient quantity to allow of an accurate examination of its properties. So far as they have been discovered, silicon appears to be more analogous to boron and carbon, than to the metals. It is apparently incapable of being vaporized; its attraction for oxygen would seem to be superior to that of boron, or carbon, for it decomposes water at common temperatures, while carbon requires for this effect a red heat. On the other hand, when the affinities of carbon are exalted by heat, it has the power of taking oxygen from boron, and even from silicon, at least when aided by iron.

Phosphorus and sulphur obviously are intimately related to each other in many properties. Their specific gravities are not very distant from each other; they are both susceptible of crystallization, are insoluble in water, volatile below the temperature of ignition, and each forms, probably, three acids with oxygen. They combine with chlorine, iodine, and hydrogen, and form with the metallic bases phosphurets and sulphurets, which have many properties in common. But phosphorus differs from sulphur in being soluble in azote, in its greater disposition to unite with oxygen, and in the property of not forming an acid with hydrogen. Its affinity for oxygen is likewise more powerful, for when water is decomposed by phosphuret of sulphur, the results are hypophosphorous acid and sulphuretted hydrogen.

The compound base, cyanogen, approaches the elementary bodies in some of its characters. Like chlorine, iodine, and sulphur, it forms an acid with hydrogen, it unites directly with radicals and constitutes compounds, some of which resemble those of chlorine in their power to decompose water; with potassium, it presents the phenomena of combustion, and it is itself inflammable, though it forms no peculiar compound with oxygen.

CCCCXCIX. The actual constitution of the acids is still a subject of speculation. After the discovery of oxygen, the researches of Lavoisier terminated in the belief, that its combinations might all be reduced to the two classes of oxides and acids. The former consisted of bases combined with a certain proportion of oxygen, and the latter of the same bodies united with a still larger proportion of oxygen. The acids were considered as simple binary compounds, some of which possessed so strong an attraction for water as never to be obtained in an insulated state. It is well known, that sulphuric and nitric acids, when uncombined, exist in the liquid form, and that when made to unite with bases, water is produced or disengaged, and it seems reasonable to suppose, that it is contained in them in the same state. This opinion of the constitution of the liquid acids was commonly, if not universally received as correct; and it is assumed by professor Berzelius and M. Gay-Lussac, that the water which is known to be present, operates as a base, and prevents such acids from acquiring and retaining elasticity. Hence, chloric acid has been stated to be composed of 1 volume of chlorine, combined with $2\frac{1}{2}$ volumes of oxygen, or as consisting of 1 proportion of the former and five of the latter, without reference to the elements of the water, which, however, is regarded, by M. Gay-Lussac, as essential to the form, if not the existence of the acid. The composition of sulphuric and nitric acids is analogous, both of them being binary compounds of oxygen with bases, while oxygen and hydrogen in the form of water are combined with them, so as in fact to

constitute compounds of an oxide with acids. This distinguished chemist has gone further, and from finding that in the analyses of *spirit of wine*, and of an inflammable liquid known by the name of *ether*, the elements of water were produced, has drawn the conclusion, that the former is composed of 1 volume of olefiant gas, and the latter of 2 volumes of the same gas combined with 1 volume of the vapour of water. It does not always follow, however, that because water or its elements are disengaged during the decomposition of a compound, that it previously existed as such in the body examined. The opinion may be maintained, that in such cases, as for example of the acids, oxygen and hydrogen, though in the proportion required for the constitution of water, are combined with the bases, so as in fact to form ternary compounds. Some years ago, this idea of the nature of acids was adopted and illustrated by Dr. Coxe of Philadelphia; they were considered by him as compounds of bases with oxygen and hydrogen, the latter constituting an essential element, and the reason assigned by him for the fact, that the binary compound of these bodies does not possess acid properties was the deficiency of a base.*

This opinion is strengthened by the discovery of a class of bodies in which hydrogen may be considered as the acidifying principle, and which have therefore received the name of hydracids.

Sir H. Davy, in his *Elements of Chemical Philosophy*, supported the hypothesis that oxygen and hydrogen, in the proportion required for the formation of water, enter as distinct elements into the composition of the liquid acids. Thus, nitric acid instead of being considered as a compound of 1 proportion of water with 1 of dry acid, consisting of 1 proportion of azote, and 5 proportions of oxygen, might be conceived to be composed of 6 proportions of oxygen, and 1 each of azote and hydrogen; chloric acid may be supposed to be perfectly analogous, and to differ from liquid nitric acid in

* *Observations on Combustion and Acidification, &c.* 1811.

containing 1 proportion of chlorine instead of 1 of azote. And more lately the subject has been discussed by him in opposition to the opinion of M. Gay-Lussac. It is remarked by him, that, if oxygen and hydrogen in the proportion in which they form water, are to be considered as passive, as neutralizing each other in all combinations, in which they exist, then almost all the vegetable acids must be considered as acids of carbon, which, though containing much less oxygen than carbonic acid, and some of them less even than carbonic oxide, have yet strong acid powers. The idea of M. Gay-Lussac respecting the mode in which the elements of water exist in combinations is regarded as pure assumption, and as opposed to the whole series of chemical facts; an acid composed of 5 proportions of oxygen, and 1 of nitrogen, is altogether hypothetical; and it is a simple statement of facts to say, that liquid nitric acid is a compound of 2 proportions of hydrogen, 1 of azote, and 6 of oxygen. Hydrogen in M. Gay-Lussac's chloric acid may be considered as acting the part of a base; and it is an important circumstance in the law of definite proportions, that when one metallic or inflammable basis combines with certain proportions of a compound, all the others combine with the same proportions. Nitric or sulphuric acid cannot be procured from the nitrates or sulphates without the intervention of bodies containing hydrogen; and if nitrate of ammonia were to be judged of from the results of its decomposition, it must be regarded as a compound of water and nitrous oxide.*

D. These points of speculation have been very ably discussed in a late interesting and profound memoir, by Dr. Murray of Edinburgh, and have led to some novel views of the constitution of acids, and the principles of acidity and alkalinity.† When water is obtained from muriatic acid gas, it does not necessarily follow, he observes, that it has pre-existed in the state of water. It is equally possible, *à priori*, that its

* Journal of Science and the Arts, vol. i. p. 283.

† Transactions of the Royal Society of Edinburgh, 1818.

elements may be present in simultaneous combination with the acid or its radical,—that the acid is a ternary compound of a radical with oxygen and hydrogen; and that it is decomposed in those processes in which water is procured, the hydrogen, with the requisite proportion of oxygen, combining to form water, and its radical, with any excess of oxygen, remaining in union with the substance, by which the change has been effected. The same view may be taken of the other acids, which appear to contain water in intimate combination, and in definite proportion.

Sulphuric acid affords water when it is submitted to the action of an alkaline base; and the quantity of this water appears to be definite, amounting to 18.5 in 100 of the strongest acid which can be procured in an insulated state; 100 parts of this acid, therefore, are considered as composed of 81.5 of real acid (consisting of 32.6 of sulphur, and 48.9 of oxygen,) with 18.5 of water. But, if instead of this view of its constitution, it be considered as a ternary compound of sulphur, oxygen, and hydrogen, its composition will be 32.6 of sulphur, 65.2 of oxygen, and 2.2 of hydrogen. In those processes by which water is obtained from it; in the action, for example, of an alkaline base, and subsequent exposure to heat, the composition is subverted by the affinities exerted; the hydrogen unites with the requisite proportion of oxygen, forming water, and the remaining oxygen with the sulphur combines with the base.

Hence, Dr. Murray infers, that a relation of the elements of bodies to acidity may be discovered, differing from what has been hitherto proposed. When a series of compounds exists which have certain common characteristic properties, and when all these compounds contain a common element, we conclude, with justice, that these properties are derived more peculiarly from the action of this element.

Upon these grounds, Lavoisier inferred, that oxygen was the principle of acidity; and M. Berthollet, and M. Gay-Lussac, that in some cases, it was equally produced by hy-

drogen, and, if Dr. Murray's view of the constitution of the acids be just, these principles must be further modified.

It is conceived by this distinguished chemist, that from the united action of the elements, viz. oxygen and hydrogen, a higher degree of acidity is acquired than from the influence of either of them alone, and sulphur is quoted as affording a striking example. With hydrogen, it forms a weak acid. With oxygen, it also forms an acid, which, though of superior energy, still does not display much power. With hydrogen and oxygen, it seems to receive the acidifying influence of both, and its acid is proportionally exalted.

Nitrogen with hydrogen forms a compound altogether destitute of acidity, and possessed of properties opposed to it. With oxygen in two definite proportions it forms oxides; and it is doubtful, if, in any proportion, it can establish with oxygen an insulated acid. But with oxygen and hydrogen in union, it forms nitric acid, a compound more permanent, and of energetic action.

Precisely the same view is taken of the compounds of carbon with oxygen, which are either inflammable, or have weak acid properties; but when the base is united, both with oxygen and hydrogen, as in the vegetable acids, bodies possessing high acid qualities are produced.

Muriatic acid itself is inferred by Dr. Murray, to present the same results, and in stating them he has offered a novel, interesting, and by no means improbable theory of the constitution of that body, and of the nature of chlorine. According to this doctrine, oxy-muriatic or chlorine gas is considered "as a compound of an unknown radical, (*Murion*, if the term may be allowed,) with oxygen, analogous in this respect to sulphurous acid, except that in the latter there is an excess of base, in the former an excess of oxygen; and oxy-muriatic acid, with the addition of hydrogen, forms the ternary compound muriatic acid, as sulphurous acid with the same addition forms hydro-sulphuric acid, with a deposition of the excess of sulphur. There is accordingly the strictest analogy

between muriatic acid, and those other acids, the sulphuric, nitric, &c. which contain both oxygen and hydrogen, while there is none, as Berzelius has remarked, between it and those, such as the prussic acid and sulphuretted hydrogen, which contain merely hydrogen. This principle solves the difficulty which has always presented itself in the relation of muriatic and oxy-muriatic acids in Lavoisier's theory of acidity,—that the latter, though it has received an addition of oxygen is inferior in acid power to the former.—The proper analogy is that of oxy-muriatic with the sulphurous acid, and the muriatic with the sulphuric, and under this point of view, there is no anomaly, but strict conformity." Dr. Murray then proceeds to show, that in their gaseous form, their specific gravity, their suffocating odour, their power of destroying vegetable colours, their solubility in water, their remaining combined with it in congelation, their acidity, their combining weights, for in Wollaston's table oxy-muriatic acid stands next to sulphurous acid, and their being attracted to the positive pole in the voltaic series, chlorine and sulphurous acid have a great resemblance to each other, while in the hypothesis of Gay-Lussac, who classes chlorine with sulphur, the only analogy of the former to the latter is in being acidified by hydrogen.

The coincidence of properties, both physical and chemical, here stated is certainly remarkable, and they strongly lead to the belief in a similarity of constitution. and as observed by Dr. Murray, any deviation from this analogy may arise from the excess of oxygen in oxy-muriatic acid.

In this theory, then, chlorine is considered as a compound of an unknown base with oxygen, and muriatic acid as a compound of this oxide with hydrogen. "It would be in vain to seek for the discovery of real muriatic acid in an insulated form. It exists no more than real sulphuric or real nitric acid."

The same view is taken of the constitution of iodine. It may be an oxide of an unknown radical, which may be acidi-

fied by hydrogen, by the addition of more oxygen, or by union both with oxygen and hydrogen. "Assuming the existence of a simple radical in muriatic acid, it resembles sulphur, phosphorus, and carbon, in forming an acid with oxygen, and one still more powerful with oxygen and hydrogen; but it differs in the peculiarity, that the proportion of oxygen to the base in the binary combination is considerably larger than in the ternary, so that the addition of hydrogen converts the one into the other: and also in its combining apparently with more numerous proportions of oxygen, than any of the acidifiable bases,—two circumstances, which, as well as the difficulty of effecting its decomposition, probably depend upon the same cause, the strength of its attraction for oxygen."

Dr. Murray then proceeds to apply this theory to the solution of the phænomena displayed by chlorine and muriatic acid in their combinations; and to state the relations of water, or its elements to the acids in general. The principles he has induced will do away the anomalies, both in the old doctrine of M. Gay-Lussac and professor Berzelius, in which water is supposed to act the part of a base to preserve the elements of an acid united; and in the new doctrine of chlorine, which refuses to admit the presence of water in muriatic acid, but allows it in all others. He remarks, that by considering oxygen and hydrogen as elements conferring acidity, a satisfactory solution is afforded of the effects produced in these cases by their joint operation; and independent of this it is much more probable, *à priori*, that such effects should arise from the action of elements so powerful, than from the agency of water, which, in its general relations, exerts such feeble powers.

This theory of the constitution of the acids, or at least a part of it was proposed by Dr. Coxe of Philadelphia in 1811. He inferred, that all the acids were compounds of oxygen and hydrogen with bases, and accounted for the absence of acid properties in water upon the principle, that it wanted a base. All his reasoning led to the opinion. that he considered the

oxygen and hydrogen as constituting parts of an acid, not as water, but as two elements of a ternary compound, of which some base composed the third.*

DI. If it be difficult to fix upon a principle of acidity, it is equally so to found the character of alkalinity upon the presence of any specific element. If oxygen be regarded as the principle of the former, it must also be considered with one exception as the cause of the latter. But it enters, likewise as an element, into the composition of bodies, which are neither acid nor alkaline; and those properties, therefore, must depend upon circumstances, in a certain degree independent of its nature. M. Gay-Lussac regards, as performing the functions of an alkali, all bodies which either completely or in part saturate the properties of acids; and as acids, all bodies that saturate the properties of alkalies; and the neutral state is supposed to result from a certain constant ratio, between bodies which possess these opposite characters. M. Gay-Lussac thinks, that the saturating property of an acid depends principally upon its radical, since the ratio only of this radical to the alkaline base is constant. Thus it is remarkable, that acids, differing both in the nature of their radicals, and the quantity of oxygen they contain, saturate the same quantity of alkali, supposing each to contain the same gaseous volume of base. This fact is illustrated in the following table.

* Observations on Combustion and Acidification.

Chloric acid	-	{	Radical	-	1	}	saturates	2	ammonia.
		{	Oxygen	-	2.5	}			
Iodic acid	- - -	{	Radical	-	1	}	- - -	2	
		{	Oxygen	-	2.5	}			
Nitric acid	- -	{	Radical	-	1	}	- - -	2	
		{	Oxygen	-	2.5	}			
Nitrous acid	-	{	Radical	-	1	}	- - -	2	
		{	Oxygen	-	1.5	}			
Sulphuric acid	-	{	Vap. of sulph.	1		}	- - -	2	
		{	Oxygen	-	1.5	}			
Sulphurous acid		{	Vap. of sulph.	1		}	- - -	2	
		{	Oxygen	-	1	}			
Hydriodic acid		{	Vap. of iodine	1		}	- - -	2	
		{	Hydrogen	-	1	}			
Muriatic acid	-	{	Chlorine	-	1	}	- - -	2	
		{	Hydrogen	-	1	}			

The neutralization of acids and alkalies in simple ratios, and that of their electrical energies where they form neutral salts, are subordinate to the property which all bodies have of combining in definite proportions; and, according to Gay-Lussac, a compound is neutral with respect to us when it refuses to unite with the acid, or alkaline particles presented to it. But the character of a compound is influenced, independently of the proportion of its elements, by the degree of condensation in volume, which they experience during their combination. Thus, the union in volume of 2 of hydrogen, of azote, or of carbon, with 1 of oxygen, and a condensation of $\frac{1}{3}$ the total volume, determines the neutral character. The combination of 1 in volume of carbon, or of sulphur, with 1 of oxygen, and a condensation of $\frac{1}{2}$ the volume of the whole, determines the acid character. But if the condensation be nothing, as in nitrous gas, the compound is neither acid, nor alkaline, though it contain equal volumes of azote and oxygen. Whence it appears, that though oxygen in general gives a neutral, acid, or alkaline character to a body, according to the

proportions combined, yet that the condensation has likewise an effect in determining this character.

There are easy methods by which these different states in some combinations may be recognized, but as they do not apply to all cases, M. Gay-Lussac proposes a new one, founded upon the principle, that whenever a neutral compound is divided into two compounds, of which one is neutral, the other must of necessity be neutral likewise. Thus, the products of the decomposition of nitrate of ammonia by heat, are water and nitrous oxide, both of which are neutral; and in the decomposition of sulphate of ammonia, all the oxygen of the acid, and all the hydrogen of the ammonia, forming water which is neutral, the sulphur and azote which remain, and which are to each other as 20 to 17.5, will form a sulphuret of azote, which ought also to be neutral. M. Gay-Lussac also thinks it ought to be admitted as a principle, that a neutral compound does not destroy the acid, or alkaline energy of another compound with which it combines. He is disposed to assign an acidifying property, not only to oxygen, chlorine, and iodine, but likewise to sulphur, phosphorus, and carbon. Hence, as the ideas of chemists have become generalized, it is difficult to give correct definitions of acidity and alkalinity; they are correlative terms, and one can be defined only by referring to the other. Yet, whatever be the definition given to these characters, the acids will be required to be divided into different groupings, because they do not all derive their acid properties from the same body. M. Gay-Lussac was thus led to arrange these bodies in two classes, the first, in which oxygen is considered as the acidifying principle, such as chloric, iodic, sulphuric, sulphurous, nitric, nitrous, phosphoric, phosphorous, carbonic, arsenic, boracic, and probably a great number of metallic oxides, which really possess acid properties; and secondly, the acids formed by hydrogen and another body, such as hydro-chloric, hydro-iodic, and hydro-sulphuric acids; to which, though it have a compound radical, we may add hydro-cyanic acid. This class

has the general name of *Hydracids*. M. Gay-Lussac seems disposed to admit likewise of a third class, the vegetable acids, the acidifying principle of which he conceives to be carbon, or carbon and hydrogen.

Besides condensation, this great chemist infers, that the arrangement of the *moleculæ* or particles has a great influence in determining the acid, alkaline, or neutral character of a compound. Thus, he remarks that the acetic acid (*acid of vinegar*) does not sensibly differ in composition from *woody fibre*, which possesses no acid properties, and, that thus two bodies composed of carbon, oxygen, and hydrogen, in the same proportions, present properties entirely different. Sugar, gum, and starch, though composed of the same elements, and combined in the same ratio, differ obviously from each other, and the difference can be accounted for only upon the peculiar arrangement of their *moleculæ*.*

Yet, in a subsequent memoir, M. Gay-Lussac endeavours to show that hydrogen may be considered as an *alkalizing* principle, and azote as an *acidifying* principle.† But, as observed by Sir H. Davy, if hydrogen be an alkalizing principle, it is strange that it should form some of the strongest acids by uniting to bodies not in themselves acid; and if azote be an acidifying principle, it is equally strange that it should form nearly $\frac{2}{10}$ of the weight of the volatile alkali. It is impossible to infer what will be the qualities of a compound from the qualities of its constituents; and, if M. Gay-Lussac's views were correct, the prussic basis of azote and carbon ought to have its acid properties diminished, and not increased, as he has proved them to be, by combination with hydrogen.

When certain properties are found belonging to a compound, we have no right to attribute these properties to any of its elements to the exclusion of the rest, but they must be regarded as a result of combination.‡

* Memoir on Iodine—translated. *Annals of Philosophy*, vol. vi. p. 187. Note B.

† *Annales de Chimie* for July, 1814.

‡ *Journal of Science and the Arts*, vol. i. p. 283.

Dr. Murray has extended the views he has taken of acidity to the subject of alkalinity. As hydrogen in some cases gives rise to acidity, so it may in other cases occasion alkalinity. Under this point of view, ammonia, in which oxygen cannot be detected, is a compound, of which nitrogen is the base, deriving its alkaline power from hydrogen; it stands, therefore, in the same relation to the other alkalies, that sulphuretted hydrogen does to the acids. The fixed alkalies, potash and soda, are considered as hydrates, that is to say, as bases united chemically with a certain proportion of water, but it is obvious, says Dr. Murray, that the elements of water may exist in combination with the base; that potash, for example, is not a compound of oxide of potassium with water, but of potassium, oxygen, and hydrogen.

The evidence in support of this doctrine, it is obvious, is of the same kind as that with regard to the doctrine applied to the acids. There is the same superior probability in favour of the conclusion that the elements of water, rather than water itself, exist in these compounds, from the consideration, that modifications of properties so important are more likely to arise from the agency of these elements, than from any action which water can exert. And that water does not exist in them, in consequence of the strength of attraction which the real alkali, as it has been considered, exerts towards it, is evident from this, that on the same principle, ammonia ought to contain combined water in its insulated form, which is not the case. The combination of water, therefore, or rather of its principles, in these compounds, depends on relations subsisting among the ultimate elements, not on an affinity exerted by the alkali itself.

The superior alkaline energy of the fixed alkalies, potash and soda, compared with the common metallic oxides, Dr. Murray thinks may arise from the joint action of oxygen and hydrogen, in the same manner as the acidity of the ternary compared with the binary acids, is increased by a similar constitution. Thus the class of alkalies will exhibit the

same relations as the class of acids. Some are compounds of a base with oxygen; ammonia is a compound of a base with hydrogen; and the fixed alkalies and alkaline earths of bases united with oxygen and hydrogen. Upon this supposition the constitution of neutral salts must be very different from that which is generally maintained; for while the hydrogen present combines with the requisite proportion of oxygen forming water, the radical of the acid, and the radical of the base, may enter into union with the remaining oxygen, and form a ternary compound. And, where hydrogen is not present, such a combination may be at once established.

If this view be adopted, neutralization is not the saturation of acid with alkali, and the subversion of the properties of one by the opposed action of those of the other; but is the change of composition of both, and the quiescence of the elements, in that proportion in which their affinities are in a state of equilibrium without any excess. The compounds, therefore, have little activity; and energy of action is restored only by the reproduction of substances, which, by their mutual attractions, tend to the same state of quiescence.

All these results, says Dr. Murray, display more fully the extensive relations of the two elements, oxygen and hydrogen. They do not act merely in opposition, as has been imagined, but more frequently in union, producing similar effects. Hydrogen is of nearly equal importance with oxygen, and the principal details of chemistry consist in their modified action on inflammable, and metallic bodies.*

* Experiments on muriatic acid gas, &c. p. 38—42.

APPENDIX.

TABLE

of the numbers representing the elementary bodies, and their compounds, mentioned in this volume; these numbers having been calculated upon the supposition that water consists of one proportion each of oxygen and hydrogen.

1. *Elementary bodies.*

Hydrogen	-	-	-	1
Oxygen	-	-	-	7.5
Chlorine	-	-	-	33.5
Iodine	-	-	-	117.7
Azote	-	-	-	13
Silicon	-	-	-	16
Boron	-	-	-	8.6
Carbon	-	-	-	5.7
Phosphorus	-	-	-	20
Sulphur	-	-	-	15

2. *Compound bodies.*

Protoxide of Chlorine	-	41	Muriatic acid	-	-	-	34.5
Deutoxide of Chlorine	-	60.5	Hydriodic acid	-	-	-	118.7
Chloric acid	-	-	-	71	Nitrous oxide	-	20.5
Perchloric acid	-	-	-	86	Nitric oxide	-	28
Iodic acid	-	-	-	135.2	Nitrous acid gas	-	43
Protochloride of iodine	-	151.2	Nitric acid	-	-	-	67.5
Deutochloride of iodine	-	184.7	Ammonia	-	-	-	16
Water	-	-	-	8.5	Chloride of azote	-	147

Muriate of ammonia	-	50.5	Phosphuretted hydrogen	-	21
Nitrate of ammonia	- -	66.5	Bi-phosph. hydrogen	-	22
Silica	- - - - -	31	Sulphurous acid	- - -	30
Boracic acid	- - -	23.6	Sulphuric acid	- - -	37.5
Carbonic oxide	- - -	13.2	Sulphite of ammonia	-	76
Chloro-carbonic acid	-	46.7	Sulphate Do.	- - - -	62
Carbonic acid	- - -	20.7	Chloride of sulphur	- -	48.5
Carburetted hydrogen	-	7.7	Sulphuretted hydrogen	-	16
Olefiant gas	- - - -	6.7	Super-sulph. hydrogen	-	31
Hypo phosph. acid	-	27.5	Sulphuret of carbon	- -	35.7
Phosphorous acid	- -	35	Cyanogen	- - - -	24.4
Phosphoric acid	- - -	50	Hydro-cyanic acid	- -	25.4
Protochloride phosph.	-	53	Chloro-cyanic acid	- -	57.9
Deutochloride Do.	- -	87			

—♦—

Capacities of gaseous bodies for Caloric.

1. *According to Dr. Crawford.*

				Equal weights.
Water	-	-	-	1.0000
Hydrogen gas	-	-	-	21.4000
Oxygen gas	-	-	-	4.7490
Atmospheric air	-	-	-	1.7900
Carbonic acid	-	-	-	1.0454
Azote	-	-	-	0.7936
Aqueous vapour	-	-	-	1.5500

—♦—

2. *According to M. M. Berard and De la Roche.—Air being unity.*

		Equal volumes.		Equal weights.	Sp. Gr.
Air	- - -	1.0000	-	1.0000	1.0000
Hydrogen	- -	0.9033	- -	12.3401	0.0732
Carbonic acid	-	1.2583	-	0.8280	1.5196
Oxygen	- - -	0.9765	- -	0.8848	1.1088
Azote	- - -	1.0000	-	1.0318	0.9691
Nitrous oxide	- -	1.3502	- -	0.8878	1.5209
Olefiant gas	-	1.5530	-	1.5763	0.9885
Carbonic oxide	-	1.2583	- -	0.8280	0.9596

Water being unity.

	Equal weights.
Water - - -	1.0000
Air - - -	0.2669
Hydrogen - - -	3.2936
Carbonic acid - -	0.2210
Oxygen - - -	0.2361
Azote - - -	0.2754
Nitrous oxide - -	0.2369
Olefiant gas - -	0.4207
Carbonic oxide - -	0.2884
Aqueous vapour -	0.8470

*3. According to Mr. Dalton.*

	Equal weights.	Equal bulks.
Water - - -	1.00	001
Hydrogen - - -	21.40	002
Oxygen - - -	4.75	006
Common air - - -	1.79	002
Carbonic acid - - -	1.05	002
Azote - - -	79	001
Aqueous vapour - - -	1.55	001

*Specific Gravities of the Elastic Fluids, that of air being taken as unity.**

Names of the Elastic Fluids.	Densities determin'd by experi- ment.	Densities by calcu- lation.	Names of the Observers.
Air - - -	1.0000		
Vapour of iode - -		3.5195	Gay-Lussac, Ann. de Chim. v. xci. p. 17.
Vap. of hydriodic ether	5.4749		Gay-Lussac.
Vap. of essence of turpen- tine - - -	5.0130		Gay-Lussac.
Hydriodic gas -	4.4430	4.4288	Gay-Lussac, Ann. de Chim. v. xci. p. 16 and 17.
Fluo-silicic gas - -	3.5735		J. Davy, Phil. Trans. 1812, p. 354.
Chloroxycarbonic gas		3.3894	J. Davy, Phil. Trans. 1812, p. 150.
Nitrous acid gas -		3.1764	Gay-Lussac.
Vapour of sulphuret of carbon - - -	2.6447		Gay-Lussac.
Vap. of sulphuric ether	2.5860		Gay-Lussac.
Chlorine - - -	2.4700	2.4216	Gay-Lussac and Thenard.
Enchlorine - - -		2.3144	Gay-Lussac.
Fluoboric gas - -	2.3709		J. Davy, Phil. Trans. 1812, p. 366.
Vapour of hydrochloric ether - - -	2.219		Thenard, Soc. d'Arc. v. i. p. 121.
Sulphurous acid gas	2.1930	2.2072	Davy, Bibli. Brit. v. iv. p. 114.
Chlorocyanic vapour		2.1113	Gay-Lussac, Ann. de Chim. v. xcv. p. 210.
Cyanogen - - -	1.8064	1.8011	Gay-Lussac, Ann. de Chim. v. xcv. p. 177.
Vap. of absolute alcohol	1.6133	1.6030	Gay-Lussac.
Protoxide of azote -	1.5204	1.5209	Colin.
Carbonic acid - -	1.5196		Biot & Arago, Mem. de l'Inst. 1816, p. 320.
Hydrochloric gas -	1.2474	1.2505	Biot & Arago, Mem. de l'Inst. 1806, p. 320.
Hydrosulphuric gas	1.1912	1.1768	Thenard & Gay-Lussac, Re- chêrch. Physico-chim. 1. p. 191.
Oxygen gas - - -	1.1036		Biot & Arago, Mem. de l'Inst. 1806, p. 320.
Deutoxide of azote	1.0382	1.0364	Berard.
Percarburetted hydrogen gas - - -	0.9784		Theodore de Saussure, Ann. de Chim. v. lxxxix. p. 283.
Azotic gas - - -	0.9691		Arago & Biot, Mem. de l'Inst. 1806, p. 320.
Gaseous oxide of carbon	0.9569	0.9678	Cruikshanks.
Hydrocyanic vapour	0.9476	0.9360	Gay-Lussac, Ann. de Chim. v. xcv. p. 150.
Phosphuretted hydrogen	0.870		Davy, Phil. Trans. 1812, p. 408.
Vapour of water (steam)	0.6235	0.6250	Gay-Lussac.
Ammoniacal gas -	0.5967	0.5943	Biot & Arago, Mem. de l'Inst. 1806, p. 320.
Protocarburetted hydro- gen gas - - -	0.5550	0.5624	Thomson, Bibl. Brit. v. iv. p. 123.
Arseniated hydrogen gas	0.5290		Tromsdorf.
Hydrogen gas - -	0.0732		Arago & Biot, Mem. de l'Inst. 1806, p. 320.

* Extracted from the *Annals of Chem.* 1816, vol. i. 213 by Gay-Lussac.

EXPLANATION OF THE PLATES.

PLATE I.

*Account of Dr. Wollaston's Scale of Chemical equivalents.** By Dr. Thomson.

This scale is of so much convenience to the practical chemist, that I seize the earliest opportunity to make it known to my readers in general. It gives the composition of any weight whatever of any of the salts contained on the scale, the quantity of any other salt necessary to decompose it, the quantity of new salt that will be formed, and many other similar things, which are perpetually occurring to the practical chemist, and cannot be answered without an arithmetical calculation. I have used such a scale for above six months, and found it attended with numberless advantages. I cannot undertake to explain the instrument, either more clearly, or in fewer words, than Dr. Wollaston has himself done in his own paper. I conceive, therefore, that the best thing I can do is to present my readers with the following extract from that paper, which contains the most material part of it, as far as the explanation of the instrument is concerned.—

“It is not my design, in the table which follows this paper, to attempt a complete enumeration of all those elements or compounds which I suppose to be well ascertained, but merely to include some of those which most frequently occur. I do not offer it as an attempt to correct the estimates that have been formed by others, but as a method in which their results may be advantageously applied, in forming an easy approximation to any object of our inquiries.

“The means by which this is effected may be in part understood by inspection of the Plate [XXII.] in which will be seen the list of substances intended to be estimated, arranged on one or the other side of a scale of numbers, in the order of their relative weights, and at such distances from each other, according to their weights, that the series of numbers placed on a sliding scale can at pleasure be moved, so that any number expressing the weight of a compound may be brought to correspond with the place of that compound in the adjacent column. The arrange-

* Dr. Wollaston's paper is published in the *Philosophical Transactions* for 1814, part i.

ment is then such, that the weight of any ingredient in its composition, of any re-agent to be employed, or precipitate that might be obtained in its analysis, will be found opposite to the point at which its respective name is placed.

“ In order to show more clearly the use of this scale, the plate exhibits two different situations of the slider, in one of which oxygen is 10, and other bodies are in their due proportion to it, so that carbonic acid being 27.54, and lime 55.46, carbonate of lime is placed at 63.

“ In the second figure, the slider is represented drawn upwards till 100 corresponds to muriate of soda; and accordingly the scale then shows how much of each substance contained in the table is equivalent to 100 of common salt. It shows, with regard to the different views of the analysis of this salt, that it contains 46.6 dry muriatic acid, and 53.4 of soda, or 59.8 sodium, and 13.6 oxygen; or if viewed as chloride of sodium, that it contains 60.2 chlorine, and 39.8 sodium. With respect to re-agents, it may be seen, that 283 nitrate of lead, containing 191 of litharge employed to separate the muriatic acid, would yield a precipitate of 237 muriate of lead, and that there would then remain in solution nearly 146 nitrate of soda. It may at the same time be seen, that the acid in this quantity of salt would serve to make 232 corrosive sublimate containing 183.5 red oxide of mercury, or would make 91.5 muriate of ammonia, composed of 6 muriatic gas, (or hydromuriatic acid) and 29.5 ammonia. The scale shows, also, that for the purpose of obtaining the whole of the acid in distillation the quantity of oil of vitriol required is nearly 84, and that the residuum of this distillation would be 122 dry sulphate of soda, from which might be obtained, by crystallization, 277 of Glauber salt containing 155 water of crystallization. These, and many more such answers, appear at once, by bare inspection, as soon as the weight of any substance intended for examination is made by motion of the slider correctly to correspond with its place in the adjacent column.

“ With respect to the method of laying down the divisions of this scale, those who are accustomed to the use of other sliding-rules, and are practically acquainted with their properties, will recognize upon the slider itself the common Gunter's line of numbers (as it is termed,) and will be satisfied that the results which

it gives are the same that would be obtained by arithmetical computation.

“ Those who are acquainted with the doctrine of ratios, and with the use of logarithms as measures of ratios, will understand the principle on which this scale is founded, and will not need to be told, that all the divisions are logometric, and, consequently, that the mechanical addition and subtraction of ratios here performed by juxta-position, corresponds in effect to the multiplication and division of the numbers by which those ratios are expressed in common arithmetical notation.

“ To others who are not equally conversant with the nature of logarithms, and consequently have not so correct a conception of the magnitudes of ratios, some further explanation of the mode in which the scale of equivalents is constructed, will, I presume, be acceptable.

“ They will observe, that the series of natural numbers are not placed at equal intervals on the scale; but that at all equal intervals are found numbers which bear the same proportion to each other. In fig. 3, some of the larger intervals alone are represented on a line similarly divided. The succession of intervals, marked A, B, C, D, E, are all equal, and at these points of division are placed numbers 1, 2, 4, 8, 16, which increase progressively by the same ratio. And since the series 3:6:12:24 increase in the same ratio of 1 to 2, these intervals *a, b, c, d, e*, are the same as the former. At another succession of different, yet equal intervals, marked F, G, H, I, are placed numbers 1, 3, 9, 27, which increase regularly by an equal ratio of 1 to 3; and by means of a pair of compasses it would be found, that the interval from 2 to 6, or from 6 to 18, (which are in the same ratio of 1 to 3,) is exactly equal to F, G, the interval between 1 and 3. As any single space represents any one ratio, so the sum of any two or three equal spaces represents a double or triple ratio. If 1 be increased three times by the ratio of 1 to 2, it becomes 8, which bears to 1, triple the ratio of 2 to 1. This ratio is therefore rightly represented by A D, which is the triple of A B.

“ The distances of the intermediate numbers, 5, 7, 10, 11, 13, &c. from 1 are likewise made proportional to the ratios which they bear to 1, and are easily laid down by means of a table of logarithms: for as these are arithmetic measures of the ratios

which all numbers bear to unity, the spaces proportional to them become linear representations of the same quantities.

“ As the entire spaces, *A D*, *A E*, represent the ratios of 8 and of 16 respectively to 1, so the difference *D E* represents the ratio of 8 and 16, which stand at *D* and *E*, to each other. And in the same manner, any other space *k l*, represents correctly the ratio of 7 to 13; so that the measure of a fraction expressed by quantities that are incommensurate is rendered as obvious to sight as that of any simple multiple. And if a pair of compasses be opened to this interval, and transferred to any other part of the scale, the points of the compasses will be found to rest upon numbers bearing the same proportion to each other as those from which the interval was transferred.

“ It is exactly in this manner, that the various points in the column of equivalents indicate the several quantities sought in any given position of the slider. The relative distances, at which the articles are placed, represent so many different openings of the compasses rendered permanent, and presented to view at once. In the table, which I shall place at the end of this communication, the relation of the various substances enumerated to each other is expressed by numbers. In the engraved scale of equivalents, the ratios of these numbers are represented by logometric intervals at which they are placed, their several positions being determined by those of their respective numbers on the slider, which is logometrically divided. Consequently, all the several points in the column of equivalents will indicate numbers in the same due proportions to each other, whatever part of the scale may be presented to them. Those who seek information may obtain it by inspection; those who already possess it may be able to correct the positions of some articles by direct comparison with the best analyses upon record, in whatever numbers the results of those analyses may happen to be expressed.”*

PLATE II.

The figures in this plate are intended to illustrate Dr. Wollaston's theory of spherical atoms,† noticed in XXVIII.

* *Annals of Philosophy*, vol. iv. pp. 176—179.

† *Philosophical Transactions* for 1813. Part i. p. 53.

Fig. 1. represents the relative position of any number of equal balls in the same plane, when gently pressed together, the figures thus produced forming equilateral triangles with each other.

Fig. 2. If a single ball be placed any where at rest upon the preceding stratum, it is evident that it will be in contact with three of the lower balls, and that the form will be a regular *tetrahedron*, having all its sides equilateral triangles.

Fig. 3. Octoedron. If four balls be placed in contact on the same plane, in the form of a square, then a single ball resting upon them in the centre, being in contact with each pair of balls, will present a triangular face rising from each side of the square, and the whole together will represent the superior apex of an octoedron, so that a sixth ball similarly placed beneath the square will complete the octoedral groupe.

Fig. 4. If the octoedral groupe, consisting of six balls, be laid upon one of its triangular sides, and consequently with an opposite triangular face uppermost, the two groupes, consisting of three balls each, are then situated precisely as they would be found in two adjacent strata of the triangular arrangement. Hence, in this position, we may readily convert the octoedron into a regular tetrahedron, by the addition of four more balls. One placed upon the top of the three that are uppermost forms the apex; and if the triangular base on which it rests, be enlarged by the addition of three more balls regularly disposed around it, the entire groupe of ten balls will then be found to represent a regular tetrahedron. From this fact it appears, that a structure, which, in the case of the octoedron was begun upon a square foundation, is intrinsically the same as that which is begun upon a triangular basis.

Fig. 5. A tetrahedron constructed upon similar principles, and exhibiting the octoedral structure.

Fig. 6. The acute *rhomboid*. This figure may be formed by applying two balls at opposite sides of the octoedral groupe, *fig. 3.*

Figs 7 & 8. If the acute rhomboid be formed with a greater number of balls, then a complete tetrahedral groupe may be removed from each extremity, and the remaining figure will be an octoedron. In *fig. 8*, the octoedral groupe is marked with a deeper outline than the tetrahedra at the extremities.

“We have seen that by the due application of spheres to each other, all the most simple forms of one species of crystal will be

produced, and it is needless to pursue any other modifications of the same form, which must result from a series of decrements produced according to known laws."

"Since then the simplest arrangement of the most simple solid that can be imagined, affords so complete a solution of one of the most difficult questions in crystallography, we are naturally led to inquire what forms would probably occur from the union of other solids most nearly allied to the sphere. And it will appear that by the supposition of elementary particles that are spheroidal, we may frame conjectures as to the origin of other angular solids well known to crystallographers."

Fig. 9. Obtuse rhomboid. By the natural grouping of spherical particles one resulting solid is an acute rhomboid represented in fig. 7, having certain determinate angles, and its greatest dimension in the direction of its axis. Now, if other particles having the same relative arrangement be supposed to have the form of oblate spheroids, the axes of which are in their shortest dimension, the resulting figure will be a rhomboid; but the measure of its angles will be different from those of the former, and will be more or less obtuse, according to the degree of oblateness of the primitive spheroid.

Dr. Wollaston thinks it at least possible that carbonate of lime and other substances, of which the forms are derived from regular rhomboids as their primitive form, may, in fact, consist of oblate spheroids as elementary particles.

Huygens explained double refraction upon the principle of the transmission of light through Iceland spar in spheroidal undulations, and these might be owing to a spheroidal form of its particles, to which the disposition to split into the rhomboidal form might likewise be ascribed.

Fig. 10. If the elementary spheroid be on the contrary oblong, instead of oblate, it is evident that by mutual attraction, their centres will approach nearest to each other when their axes are parallel, and their shortest diameters in the same plane. The consequence would be that a solid so formed would be liable to split into plates at right angles to the axes, and the plates would divide into prisms of three or six sides with all their angles equal, as occurs in phosphate of lime, beryl, &c. The figure here represented is the *Hexagonal prism*.

Fig. 11. The Cube. Let a mass of matter be supposed to consist of spherical particles, all of the same size, but of two different kinds in equal numbers, represented by black and white balls; and let it be required that in their perfect intermixture every black ball shall be equally distant from all surrounding white balls, and that all adjacent balls of the same denomination shall also be equidistant from each other. These conditions will be fulfilled, if the arrangement be cubical; and the particles will be in equilibrio. This figure represents a cube formed of four black balls, and an equal number of white balls. The four black balls are all in view. The distances of their centres being every way a superficial diagonal of the cube, they are equidistant, and their configuration represents a regular tetraedron; and the same is the relative situation of the four white balls. The distances of dissimilar adjacent balls are likewise evidently equal; so that the conditions of their union is complete, as far as appears in the small groupe; and this is a correct representative of the entire mass, that would be composed of equal and similar cubes.

It is well known that the mineral called *boracite* is electric, and that it exhibits no less than four pairs of poles. Dr. Wollaston suggests, that a possible origin of these curious polar arrangements may be traced in the structure here represented; for it will be seen that a white ball and a black one are regularly opposed to each other at the extremities of each axis of the cube.

From the nature of the subject, the fact that crystals are formed of elementary particles, which, in all cases are spherical, can never be demonstrated, but the principles of the theory may be considered as established by the researches of Dr. Wollaston and Mr. Daniell. Its simplicity and elegance are so great, that the mind is almost irresistibly impelled to grant its assent, for, to use the language of Mr. Daniell, "another analogy is thus opened to the admirers of the simplicity and beautiful connexion of the order of the universe, who will recognize in the invisible and scarcely imaginable atoms of a crystal, the same forms which in incomprehensible magnitude roll their majestic courses in the planetary system."

PLATE III.

Fig. 1. The appearance of the surface of a mass of alum, prepared according to Mr. Daniell's process (XXVII.) The figures represent right-angled parallelograms, and forms of the same class.

Fig. 2. Represents the octoedral faces of the crystals when the mass is inclined at an angle of 60° .

Fig. 3. The Air-thermometer of Sanctorius, described in paragraph LXXXII. p. 68.

Fig. 4. Leslie's Differential thermometer, noticed in paragraph LXXXII.

Fig. 5. An apparatus contrived for the purpose of showing, that liquids are imperfect conductors of heat, and which is alluded to in paragraph CXXI, p. 116. It consists of a common chemical stand, an arm of which terminates in a ring of brass or iron. Upon this is supported a glass funnel, into which has been cemented an air-thermometer, terminating in a convenient reservoir, and having a scale of degrees attached to it. Water is poured into the funnel until it rises above the bulb, as represented by the dotted line, a quantity of ether is then added and inflamed.

Fig. 6. The *Cryophorus*. (CXXII.) The internal diameter of the tube should be about $\frac{1}{8}$ of an inch, and that of the bulbs about 1 inch. Care should be taken not to fill more than $\frac{1}{2}$ of the bulb with water, otherwise it will be liable to burst by the expansion of the liquid in freezing.

Fig. 7. *Apparatus for distillation* (CXVII.) from Henry's Experimental Chemistry. It consists of a stand with a lamp attached to it; the arm supports a retort, (*a*) the body, (*b*) the tubulure, (*c*) the neck, inserted into a quilled receiver, (*d*) supported on the ring of a second stand, and opening into a receiver (*e*), resting upon a block of wood.

Fig. 8. *Alembic*. *a*, the body, *b*, the capital, or head, having a groove at the lower part, which directs the liquid into the tube *c*; referred to in CXVII.

PLATE IV.

Fig. 1. Woulf's Distilling Apparatus, par. CXXVII.—It consists of a receiver, and a series of three-necked bottles, connected with each other by tubes, bent twice at right-angles. *a*, a small furnace; *b*, a receiver supported in a sand bath; from the orifice proceeds a tube *d*, bent twice at right angles, and opening under the surface of water in the first bottle *c*; from the opposite orifice of the same bottle there passes a second tube of the same form which terminates under the surface of the liquid in the second bottle, and in this way any series of bottles *c, c, c*, may be connected by the tubes *d, d, d*, the last opening into a jar *e*, partly filled with water.

Now supposing these to be the only parts of the apparatus, the joinings to have been made air-tight, and heat to have been applied to the receiver, the elastic-fluid produced during the distillation will rise into the vessel, and be pressed from it, through the right-angled tube, into the first bottle; and as the mouth of the tube opens below the surface of the liquid, for example water, the gaseous body in rising through must come extensively into contact with it, and if any affinity exist between them, the air will be condensed, until the water is saturated. The excess of gas will then pass unaltered in form into the space above, and in consequence of its elasticity, be pressed through the second tube into the next bottle; there the same process will go on, until the saturation of the water is effected; it will then be forced into the third, and thence into the jar *e*, the water of which may be occasionally changed, when it is wished to prevent the gas from escaping into the apartment. It is obvious from this arrangement, that the water or other liquid must afford a degree of resistance to the passage of the elastic fluid, proportional to its pressure, and that this pressure must be increased with the number of bottles. By these means a larger quantity of the gaseous fluid will be condensed. But when the heat is withdrawn and the temperature* of the receiver has fallen to that of the air, the elastic fluid contained in it must be proportionally reduced in volume; the equilibrium of expansion between the air within the apparatus, and the external air, will be destroyed, a part of the pressure upon the air in the first bottle *c* being removed, it must expand, and by

pressing upon the fluid below, force it to take a retrograde direction through the first right-angled tube into the receiver *b*; the same effect must be produced upon the air contained in the other bottles; they, by their increased elasticity will press upon the liquid, and cause it to pass into the bottles to supply the vacuum behind, and the pressure of the atmosphere must operate in the same way upon the water in *e*; so that a current of liquid will be established from the jar *e*, to the receiver *b*, until the equilibrium in the pressure of the air without, and the resistance of the elastic fluid within, is re-established. The liquid by being thus forced into the receiver may either break the vessel, or frustrate the object of the experiment. Now in order to prevent this accident, a third mouth has been added to each of the bottles, into which is inserted a tube open at both ends, and which from its office is called a *tube of safety*. The lower mouths of the tubes, *s, s, s*, are immersed just below the surface of the liquid. It is apparent, that if any diminished pressure in the air contained in the first bottle *c* were to take place, the air in the second would expand and force the water through the second right-angled tube into the first bottle, but before the water could rise from the mouth of the tube to the first angle, the pressure of the air, through the tube of safety in the first bottle, would press upon the surface of the water at its lower part, and as the column of water there is much shorter than the column must necessarily be in the second tube *d*, in order to reach the first bottle, the atmospheric air must overcome its resistance soonest, and supply the vacuum in *c*, before it can be done by the water from the second. If, on the contrary, any sudden expansion should take place in the air contained in the bottles, a pressure would be exerted upon the liquid, and a proportional quantity would be forced up the tubes *s, s, s*; and as the tube *s* is shorter than that leg of the first tube *d*, which opens into the first bottle *c*, the water would flow out of it before it rose to the first angle in *d*. This arrangement, however, supposing a vacuum to be formed in *b*, would not prevent the water from flowing into it through the tube *d*; hence, a tube of safety has been added to the receiver *b*. It differs in form from the others, because, being connected with the receiver, it could not be conveniently immersed under the surface of the

materials employed for distillation. This instrument which is commonly known by the name of *Welter's tube of safety*, is a glass tube bent twice at right angles, having a bulb blown in the middle, and a reservoir at the top. The lower part, which is likewise open, is cemented into the mouth of the receiver, and water or mercury is poured into the reservoir, until it fills about one half of the bulb. The connexion between the receiver and the external air is thus destroyed; but, if any sudden expansion in the included air should take place, a portion of it must be forced up the tube, it would press upon the surface of the liquid in the bulb, cause it to rise into the reservoir at the upper end, and then the air by its specific levity would pass through it, and the excess would thus be discharged into the atmosphere. If, on the contrary, a contraction in the air within the receiver should take place, a portion of atmospheric air would pass down the tube, press the fluid into the bulb, rise through it, and thus get into the receiver.

The common method of arranging this apparatus, is to connect the three-necked bottles with a tubulated receiver, i. e. a receiver with two orifices, the one horizontal, and the other vertical, the beak of a retort being cemented into the former, and the first right-angled tube into the latter. The body of the retort is supported upon the ring of a chemical stand, and the distillation may be conducted by a common spirit or Argand lamp.

Though this arrangement be complicated, an apparatus consisting of a retort, receiver, and one three-necked bottle, with tubes, is very useful to the practical or experimental chemist.

Fig. 2. Apparatus for exhibiting the properties of Radiant caloric. In the focus of one of the reflectors is supposed to be placed a heated ball, and in the focus of the other, the bulb of an air-thermometer; and the direction of the rays from the former to the latter is marked by the dotted lines.

Fig. 3. Electrometer, described in par. (CLXXII.)

Fig. 4. *Coulomb's Electrical balance*, already described. (CLXXII.)

Fig. 5. *Condensing electrometer.* (CLXXVIII.)

Fig. 6. *Leyden jar.* (CLXXVII.)

PLATE V.

Fig. 1. The pile of Volta. (CXC.)

Fig. 2. The common Trough, or battery. (CXCI.)

Fig. 3. The Trough of Wedgewood's ware. The plates are here represented as placed upon the iron stands; and the trough as protected by a case of wood.

Fig. 4. De Luc's Electric column, with ringing apparatus inclosed in a glass jar, described at page 175.

Fig. 5. Dr. Wollaston's apparatus for decomposing water by voltaic electricity, and for collecting the gases separately. It consists of a wine-glass, perforated at opposite sides, through which are passed two wires of platina, the external portions being connected with brass knobs, and the internal protected by glass tubes cemented to the sides of the vessel. When it is to be used, water is poured into it until it rises above the end of the wires, the receivers are then filled with water, and inverted over them, so that when connected by the outside knobs with the voltaic battery, the positive wire shall be in one receiver, and the negative in the other. This apparatus will be found very convenient.

Fig. 6. A dissected pile, described at page 194, for the purpose of illustrating one of the theories of electrical excitation in voltaic arrangements.

Fig. 7. A figure from Mr. Donovan's Work, intended to illustrate the decomposition of water by voltaic electricity; and described p. 208.

Fig. 8. Common eudiometric, or detonating tube; see p. 168.

Fig. 9. An apparatus, from Davy's Elements of Chemical Philosophy; see p. 162.

PLATE VI.

Fig. 1. Gazometer. This apparatus is usefully employed in the collection, and preservation of the gases which are not absorbable by water. It consists of a cylindrical vessel *d*, of the capacity of two or three cubic feet, and formed of japanned tin. At the upper edge on one side is a tube furnished with a stop-cock *a*, which passes along the side to the bottom of the cylinder, and is

made to meet a tube fixed in the centre of the vessel, and rising to the same height as the stop-cock at *a*. This middle tube is also connected with another, which passes along the bottom and opens externally at *b*, where it is furnished with a stop-cock. In the cylinder moves a receiver *c*, of nearly the same capacity, which is balanced by the weights *e, e*, and which is likewise furnished with a guage divided into cubic inches. When this instrument is to be used, water is to be poured into the outer vessel *d*, until it rises nearly upon a level with the mouth of the internal perpendicular tube, one of the stop-cocks at *a*, or *b*, being open, the receiver is pressed down, the atmospheric air gradually escapes through the tube, and the receiver at length rests upon the mouth of the tube. It is now filled with water, and the tubes are closed. The vessel from which the gas is passing is then connected with *a*, or *b*, as is most convenient, the air rises into the receiver, and forces it up from the water; in this way, it becomes filled with the gas, and if there be any excess, it escapes by the sides.

Gazometers have been made with arms which were hollow, and which contained the weights necessary to balance the receiver, but they are less convenient than the one here represented, because, when the cords are by accident removed from the pulley, it is less easy to replace them.

By connecting appropriate tubes with one of the stop-cocks *a*, or *b*, it is obvious that the gazometer may be conveniently employed as a blow-pipe, or for breathing, or transferring gases.

Fig. 2. The common water trough, or Hydro-pneumatic apparatus. This is an indispensable instrument in the laboratory. It was invented by Dr. Priestley. Its construction, and the mode of using it, are perfectly simple. It consists of a box of mahogany of a convenient size, lined internally with sheet lead, near one end are placed ledges upon the opposite sides, having a sufficient space between them to allow of the passage of a shelf of wood perforated in several places with holes. The shelf is thus kept firm and in a horizontal position. Water is poured into the trough until it rises above the surface of the shelf, the depth depending upon the size of the trough and of the vessel to be filled. A receiver is then filled with water by inverting it in the trough.

and it is placed over one of the holes in the shelf, its mouth being immersed under the water. The beak of the retort or a tube passing from the vessel in which the gas to be collected is formed, is placed opposite to the hole under the shelf, and the gas as it issues rises through the water into the receiver, and displaces the liquid with which it was previously filled. A trough of this kind, about 10 inches in depth, and 20 in length, furnished with castors to allow of its being easily moved, and with a stop-cock to draw off any excess of water, will be found sufficiently large for a great majority of experiments with the gases.

Fig. 3. Gas-holder. This instrument will often supply the place of a gazometer. It is composed of a cylindrical air-tight vessel, of japanned tin, capable of holding from one to two cubic feet of air. Through the centre there passes a tube which opens near the bottom, while to the upper part is connected a funnel for containing water. On one side at the bottom of the cylinder is a short tube, entering somewhat obliquely and opening into the cavity. Upon the upper surface of the cylinder is supported, by iron stands, a reservoir of the depth of 3 or 4 inches, which is intended to contain water; and a communication between this reservoir, and the body of the vessel, is formed by a tube, parallel with the larger tube, and furnished with a stop-cock. Near the upper part and on one side of the cylinder is an aperture into which is screwed a cock which may be connected with a jet, or a tube through which the gas in the vessel may be transferred to a receiver. When this apparatus is to be used, the tube at the bottom is closed by a cork or a brass cap, the stop-cock below the funnel is to be opened, and water is to be poured into it; the liquid passes into the cylinder and presses out the atmospheric air, through the perpendicular tube connected with the reservoir, or the opening at the side. When the vessel is filled, the stop-cocks are all closed, the mouth of the lower tube is opened, and the beak of the retort, or the tube leading from the vessel from which the gas is passing, is inserted into it; the air rises into the body of the vessel and displaces the water, which escapes from the lower orifice. When thus filled, the mouth is to be closely stopped. The air is transferred from this vessel by the pressure of water in the funnel, the quantity of water admitted into the cylinder being regu-

lated by the stop-cock; and if the communication by the short tube between the cylinder and the reservoir be made, the air may be caught in a receiver placed over the mouth of the tube in the reservoir. If the gas-holder be filled with oxygen, it may be propelled from a jet through the flame of a spirit-lamp, and it will constitute the powerful blow-pipe of Dr. Marcet.

Fig. 4. An apparatus invented by Mr. Newman of London, which combines the advantages of the common mercurial trough with those of Pepys' mercurial gazometer.

It requires about 70 lbs. of mercury to fill it. The trough has a cavity in the middle, large enough to fill a jar 10 inches long, and $2\frac{1}{2}$ wide; and there is a shelf on each side, three inches in width, to support vessels containing gas. Opposite to three indentations on the edge of the trough, are three holes in one of the shelves, into which the beaks of retorts liberating gas are to be introduced; or a sliding shelf with apertures may be fitted across the cavity for the same purpose. The gazometer is at one end, and sunk below the level of the trough. It is capable of containing 50 cubic inches. A tube, connected with the gazometer at the lower part is made to ascend, and passing up through the mercury in a corner of the trough, at about an inch above, it bends down again, and terminates between its surface. If the gas is contained in the gazometer, it may be transferred to air-jars in the trough, by filling them with mercury, placing them over the end of the bent tube, and giving pressure to the gazometer. The air will pass from it along the tube into the jar. By the bend in the tube, the mercury is prevented from passing into the lower part of the gazometer, while at the same time the gas is allowed a free passage. All inconvenience is prevented by means of a stop-cock, which shuts off the communication between the receiver and the trough, preventing at the same time the escape of air from the gazometer, and of mercury into it. A sliding shelf is fixed beneath the trough to support a spirit-lamp under a retort, or for other purposes. A detonating tube and spring are also attached to the apparatus by a clamp and screws, and may be fixed on any side of the trough. The whole apparatus is of iron, excepting sometimes the pillars which support it, and which may be of brass.

It is not more than 18 inches in length and height ; and it is placed in a large japanned tray to collect scattered mercury.

When gas is to be collected in the gazometer, the beak of the retort is placed below the surface of the mercury, in the cup at the bottom of the apparatus, and having a bell-shaped vessel immersed in the mercury immediately over it.

Fig. 5. Cloud's compound blow-pipe ; *a*, a cylindrical tin vessel, about 18 inches in length and diameter, divided in the middle by two partitions of tin, with a space of half an inch, or an inch between them, so as to form two distinct reservoirs ; *b*, a tube inserted somewhat obliquely into the lower part, in a manner similar to that of the gas-holder. There is, of course, one for each reservoir ; *c*, a conical tin funnel, furnished with a stop-cock, and connected with a tube, which immediately below divides into two, each running down by the side of a partition, and opening at the lower part into its appropriate reservoir. Opposite to the funnel are two tubes, *d, d*, with stop-cocks, and connected one with one reservoir, the other with the other reservoir. Into these tubes are fitted the tubes *e*, which shortly meet in a cone, a section of which is represented at *f* ; the airs are thus mingled, and are then made to issue through a capillary tube drilled through a wire of silver, and inserted into the cone. The lower tubes being accurately closed, the apparatus is filled with water in the same way as the gas-holder ; the stop-cocks above are then closed, the corks below are taken out, and one reservoir is filled with hydrogen, and the other with oxygen. The tubes are afterwards accurately closed. The gases are propelled out of them by pouring water into the funnel, and opening the stop-cocks at *d, d* ; when substances are to be exposed to its action, the cock connected with the hydrogen should be first opened, the hydrogen is to be inflamed, and the body heated by it ; afterwards, the oxygen may be gradually let off, and mixed with the hydrogen, by which the temperature will be rendered intensely high.

Fig. 6. Brooke's blow-pipe, as adapted by Dr. Clarke to the combustion of oxygen and hydrogen gases. *a*, a box of strong sheet copper rendered air-tight ; *b*, a brass cylinder, having at its upper and lower ends, sections of cane, or wire-gauze fitted into it ; or it may be filled with fine wire-gauze ; *c*, a tube furnished

with a stop-cock, into which is fitted, by means of a screw, a second tube of copper having a capillary orifice, and furnished at the other end with a swivel joint, to allow of the direction being varied. *d*, the condensing syringe, with a stop cock. *e*, the bladder connected with it, and filled with a mixture of 1 volume of oxygen, and 2 of hydrogen. When it is to be filled, the bladder is to be screwed on to the syringe, the stop-cock at the bottom is opened, and that at *c* closed. The piston is raised and depressed, by which the explosive mixture is crowded into *a*. If sufficiently charged, the stop-cocks attached to the syringe and the bladder are to be turned, that of the tube *c* is to be opened, and the gases are to be directed through the flame of a spirit-lamp.

ERRATA, &c.

The reader is requested to notice the following corrections.

- Page 35, line 18, for *force*, read *forces*.
58, 1, after undecompounded bodies, add *combine*.
88, 6, for *Crawford*, r. *Irvine*.
89, 13, for *found*, r. *formed*.
101, 18, for *give*, r. *gives*.
105, 11, for 165° r. 65°.
125, 6, from the bottom, dele *Reller*.
143, 9, from the bottom, for *pendicular*, r. *perpendicular*.
161, last line but one, for *is*, r. *are*.
221, 26, for *forces*, r. *force*.
319, 18, for *Saltpetriere*, r. *Salpêtrière*.
349, 10, after *It may also be*, add *analyzed by*.
420, 6, for *hypophosphorous acid*, r. *phosphorous acid*.
425, 21, in a few copies, for *odides*, r. *Iodides*.

N. B. The calculation of the minuteness of the particles of light, page 141, which has, by mistake, been attributed to M. Hüy, was made by Mr. Bowditch of Salem, from the formula of that philosopher.

Fig. 1.

Fig. 2.

Fig. 3.

CHEMICAL	EQUIVALENTS
Abbreviations	
d. Dry	
c. Crystallized	
ox. Oxid	
carb. Carbonate	
M. Muriate	
N. Nitrate	
S. Sulphate	
W. Water	
Azote	
Sulphur	
Ammonia	
2. Water	
Magnesia	
Carbonic acid	
Muriatic acid d.	
lime	
Nitrous gas	
Soda	
Zinc	
ox. Iron	
Sub-Carb. Ammonia	
Potassium	
Red Ox. Iron	
ox. Zinc	
5. Water	
Potash	
carb. Lime	
Sub-Carb. Soda d.	
M. Ammonia	
M. Lime d.	
M. Soda	
S. Magnesia d.	
7. Water	
S. Lime d.	
S. Soda d.	
M. Potash	
Bi-Carb. Soda	
Seloute 2W. c.	
10. Water	
carb. Barites	
N. Potash	
M. Barites d.	
Red Oxid y	
S. Barites	
S. Magnesia (c 7W.)	
N. Barites	
Corros. Lead	
S. Iron c 7W.	
M. Lead	
S. Zinc c 7W.	
Oxalate Lead	
N. Lead	
2. Mercury	
Protoxid y	
Calomel 2 y	

CHEMICAL	EQUIVALENTS
Abbreviations	
d. Dry	
c. Crystallized	
ox. Oxid	
carb. Carbonate	
M. Muriate	
N. Nitrate	
S. Sulphate	
W. Water	
Azote	
Sulphur	
Ammonia	
2. Water	
Magnesia	
Carbonic acid	
Muriatic acid d.	
lime	
Nitrous gas	
Soda	
Zinc	
ox. Iron	
Sub-Carb. Ammonia	
Potassium	
Red Ox. Iron	
ox. Zinc	
5. Water	
Potash	
carb. Lime	
Sub-Carb. Soda d.	
M. Ammonia	
M. Lime d.	
M. Soda	
S. Magnesia d.	
7. Water	
S. Lime d.	
S. Soda d.	
M. Potash	
Bi-Carb. Soda	
Seloute 2W. c.	
10. Water	
carb. Barites	
N. Potash	
M. Barites d.	
Red Oxid y	
S. Barites	
Magnesia c 7W.	
N. Barites	
Corros. Lead	
S. Iron c 7W.	
M. Lead	
S. Zinc c 7W.	
Oxalate Lead	
N. Lead	
2. Mercury	
Protoxid y	
Calomel 12 y	

F	A
1	
2	B
3	a
4	C
5	
6	b
7	
8	D
9	
10	
11	
12	c
13	
14	E
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	

2



3



4



1



6



7



5



8



9



10



11



Fig. 1.



Fig. 2.



Fig. 3.



Fig. 4.



Fig. 5.

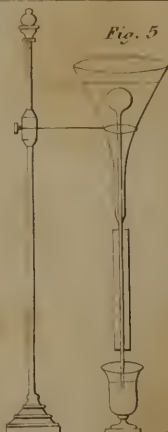


Fig. 6.

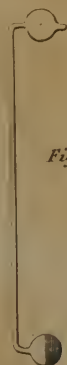


Fig. 7.

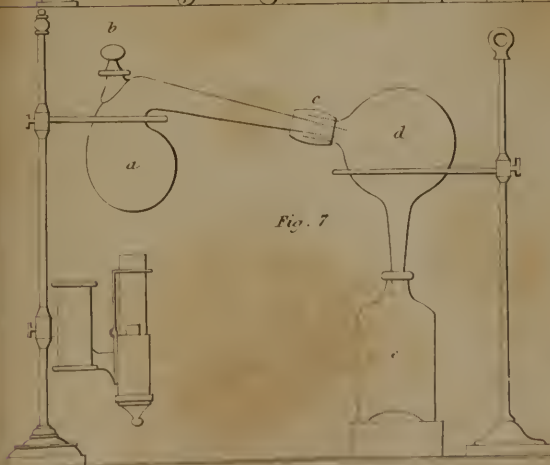


Fig. 8.



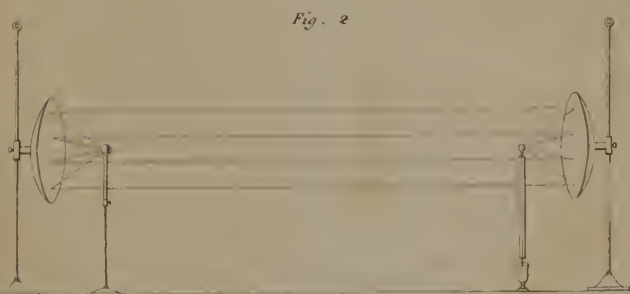
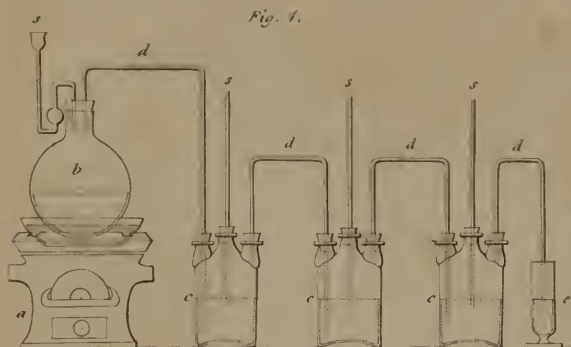


Fig. 3



Fig. 4

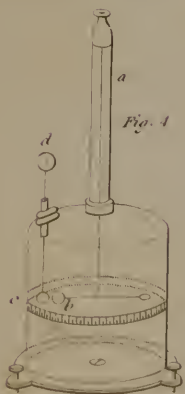


Fig. 6



Fig. 5



Fig. 1



Fig. 2

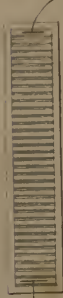


Fig. 3

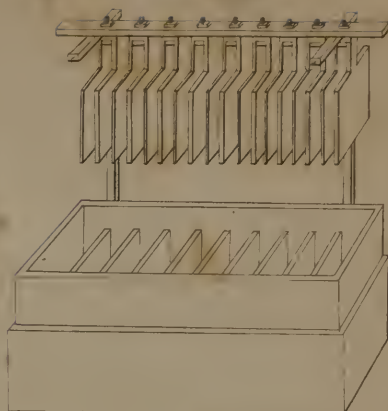


Fig. 4



Fig. 5



Fig. 6

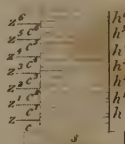


Fig. 8



Fig. 7

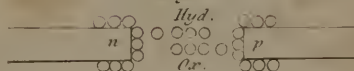


Fig. 9

